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RESEARCH, DESIGN, FABRICATION, AND FIELD TESTING OF 50' x 80' AIRCRAFT MAINTENANCE HANGARS AND 30' x 45' GENERAL PURPOSE SHELTERS

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DECEMBER 1970

DEPUTY FOR TACTICAL WARFARE
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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13. ABSTRACT

Aircraft Maintenance Hangars (50 to 60' span) and General Purpose Shelters (24 to 30' span) are needed by the Air Force as part of the inventory of mobility equipment. Several concepts are presented. Studies were made for hangars utilizing double curvature modular panels which, when joined together, would form a structurally sound vault. Panels were fiberglass reinforced polyester skins on 1-3/4" thick paper honeycomb cores. Panel sizes were limited by the 463L pallet system. The complexity of integral connecting hardware required to transmit the design stresses rendered this approach uneconomical. A variation utilizing aluminum skins on 3" thick single curvature cores resulted in excessive cubage in the packaged mode. A concept utilizing sectional arches of aluminum I-beams and 3/4" thick modular sandwich panels proved much more successful. Panels in this concept are faced with sheet aluminum and have polystyrene foam or paper honeycomb cores. Arch segments are connected with pairs of forged steel hinges, and camlocks fasten panels to arches. Variable length spacers between arches and waterproof fabric flashing allow for adjustment to minor terrain variations. Identical components are used to form the vaults of a 58' span hangar and a 30' span utility shelter. Standard off-the-shelf components are used extensively. (con't under No. 14.)

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Hangars, Aircraft Maintenance, 50' to 60' Span, Air Transportable						
Shelters, General Purpose, 24' to 30' Span, Air Transportable						
Panels, Modular, double-curvature						
Modular Construction for medium and long span Hangars and Shelters						

13. Abstract (con't)

A full size prototype hangar arch was static load tested and full size hangars and utility shelters were constructed and field tested. A long span (88') variation of the 58' span hangar is being designed and will be reported in another volume under this contract.

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RESEARCH, DESIGN, FABRICATION, AND FIELD TESTING OF 50' x 80' AIRCRAFT MAINTENANCE HANGARS AND 30' x 45' GENERAL PURPOSE SHELTERS

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FOREWORD

This is part one of the final report of the work on Air Force Contract AF33(615)3242 "Research, Design, Fabrication, and Field Testing of 50' x 80' Aircraft Maintenance Hangars and 30' x 45' General Purpose Shelters". The contract was initiated under Project 8174 "Aerospace Ground Support", Task 817410, "Aerospace Site Support". This report covers all work performed under the basic contract and modifications S/A #3, 15 May 1967 and S/A #11, 25 February 1969 with the following exceptions:

(1) Work directed toward modification of composite materials for possible use in the personnel shelter developed by this contractor under contract F33615-67-C-1259. This work is covered in the final report of that contract as authorized by SA/P018(70-1415) 17 November 1969 of contract F33615-67-C-1259.

(2) The testing of 16' x 32' personnel shelters developed under contract AF33(615)1285. This work was reported in Volume II of the final report of that contract (AFAPL-TR-65-116 Vol. II).

(3) Work on the design and prototype section production of a larger hangar for aircraft of the F-111 size. This is reported in another volume.

In addition to the work under contract AF33(615)3242, this report covers that portion of the work performed on the 24' x 40' shelter (subsequently designated "Utility" or "General Purpose" shelter) under contract F33615-67-C-1259 after 8 August 1967. On that date, the Air Force Technical Monitor made a final design decision concerning the utility shelter. The approved design used many of the components of the hangar; the utility shelter became, in effect, one of a family of shelters using a design concept which originated with the hangar.

Work conducted between 15 October 1965 and 15 November 1969 is covered by this report.

Work was performed at the College of Design, Architecture and Art of the University of Cincinnati.

This report was prepared by Professors James M. Alexander of the Department of Industrial Design and Karl H. Merkel of the Department of Architecture, Principal Investigators; John R. McKnight, Project Leader and Dr. Bahram Bahramian, Engineering Consultant.

In addition to the authors, the following contributed significantly to the work under the contract: Professor Joseph M. Ballay, Research Assistants Lawrence Fabbro, Lawrence Spreckelmeier, and Harry Sparks, and several upperclass co-op students of the college.

The work performed under the contract was administered under the direction of the Air Force Aero Propulsion Laboratory, APFT, Wright-Patterson Air Force Base, Ohio. The Air Force Project Engineer was Mr. Steven P. Shook from 15 October 1965 to October 1969 at which time the Deputy for Tactical Warfare, ASD, assumed responsibility and Captain Richard W. Matzko became the Project Engineer.

This report was submitted by the authors, James M. Alexander, Karl H. Merkel, John R. McKnight and Dr. Bahram Bahramian April, 1970.

This technical report has been reviewed and is approved.

John E. Catlin, Jr., Lt Col, USAF
Director, Bare Base Equipment SPO
Deputy for Subsystems Management

ABSTRACT

Aircraft Maintenance Hangars (50 to 60' span) and General Purpose Shelters (24 to 30' span) are needed by the Air Force as part of the inventory of mobility equipment. Several concepts are presented. Studies were made for hangars utilizing double curvature modular panels which, when joined together, would form a structurally sound vault. Panels were fiberglass reinforced polyester skins on 1 3/4" thick paper honeycomb cores. Panel sizes were limited by the 463L pallet system. The complexity of integral connecting hardware required to transmit the design stresses rendered this approach uneconomical. A variation utilizing aluminum skins on 3" thick single curvature cores resulted in excessive cubage in the packaged mode. A concept utilizing sectional arches of aluminum I-beams and 3/4" thick modular sandwich panels proved much more successful. Panels in this concept are faced with sheet aluminum and have polystyrene foam or paper honeycomb cores. Arch segments are connected with pairs of forged steel hinges, and camlocks fasten panels to arches. Variable length spacers between arches and waterproof fabric flashing allow for adjustment to minor terrain variations. Identical components are used to form the vaults of a 58' span hangar and a 30' span utility shelter. Standard off-the-shelf components are used extensively. A full size prototype hangar arch was static load tested and full size hangars and utility shelters were constructed and field tested. A long span (88') variation of the 58' span hangar is being designed and will be reported in another volume under this contract.

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ABBREVIATIONS

al	Aluminum
AFTM	Air Force Technical Monitor
E	Modulus of Elasticity
I	Moment of Inertia
mil	.001 inch
O.D.	Olive Drab (color)
ASD	Aeronautical Systems Division
in	inch, inches
n.a.	Neutral Axis
M	Moment
psi	Pounds per Square Inch
psf	Pounds per Square Foot
S/A	Supplemental Agreement
ft	foot, feet
mph	miles per hour
vel.	Velocity
G	Gravity
H/L	Height/Length
max.	maximum
wgt.	weight
oz.	ounce, ounces
cu ft	cubic foot, feet
sq ft	square foot, feet

I

INTRODUCTION

Experience of the Tactical Air Command demonstrated a need for better shelters than those available as "Grey Eagle" equipment. Included in the specialized shelter needs was a lightweight, easily-erectable, aircraft field maintenance hangar.

Under Air Force Contract AF33(615)1285, the University of Cincinnati developed several hangar concepts. Further investigation of these concepts and generation of other new concepts were prime objectives of the contract for which this is the final report.

Other objectives of the contract were to fabricate and test prototype full size span sections (arches) of the selected concept; build a full size hangar; field testing of shelters; and, as spelled out in subsequent amendments, build a second full size hangar and refurbish the first hangar incorporating improvements over the first prototype.

The work under this contract was performed by a group within the College of Design, Architecture and Art currently designated as the Design Research Collaborative. Composition of the group involves Industrial Design and Architecture faculty members and graduates and cooperative students from the Departments of Industrial Design, Architecture, and Mechanical Engineering. Very significant is the contribution of a consulting civil engineer.

Organization of this report is essentially along chronological lines. It deals first with a review of concepts and determinations of the concept to receive detailed study. Next it deals with the change from the previously selected design to still another design and, finally the production and testing of full scale sections and prototypes based on the final hangar and utility shelter designs. Certain appropriate detailed structural analyses are incorporated within the report and as appendices to the report.

Though not covered by this report, two follow-on developments should be noted:

(1) Quantity procurements of the hangars and utility shelters designed by the University of Cincinnati were initiated by the Air Force, and production items have been delivered by the Brunswick Corporation. Several of these production models underwent tactical use in the TAC field exercise at North Field, South Carolina in October, 1969.

(2) The University of Cincinnati has been awarded another Air Force Contract (F33615-69-C-1719) to develop advanced lightweight portable structural concepts for shelters, hangars, and maintenance docks.

TABLE I. CHRONOLOGY OF CONTRACT OBJECTIVES

AF33(615)3242

CONTRACTUAL	OBJECTIVES	REPORT REFERENCES
Basic Contract 15 October 1965	1. Develop new hangar concepts	Sections II, III, IV, this report
	2. Fabricate scale models and one full size 50' x 80' hangar	Sections III, VI, VII, this report
	3. Field test full size hangar	Section VII, this report
	4. Investigate new materials for a more rugged 16' x 32' shelters (similar to the type developed under AF33(615)1285)	Appendix E, this report
	5. Provide personnel for climatic testing of 16' x 32' shelter	Reported AFAPL-TR-65-116, Vol. II, Aug. 1968
S/A 3 - 15 May 1967	1. Fabricate 2 prototype arches	Section VI, this report
	2. Fabricate 1 additional full size hangar	Section VIII, this report
S/A 11 - 28 January 1969	1. Investigate new materials for a more rugged 13' x 35' shelter (as developed under F33615-67-C-1259)	Being reported in final report Contract F33615-67-C-1259
	2. Refurbish full size hangar #1	Section VIII, this report
	3. Design modification lists for production shelters	Section VIII, this report
	4. Design hangar for F-111 aircraft	To be reported in a later volume this report
	5. Fabricate 2 arches and 2 end walls for F-111 shelter	To be reported in a later volume this report

II

REVIEW OF CONCEPTS

A. CONCEPTS DEVELOPED UNDER EARLIER CONTRACT

Under Air Force Contract AF33(615)1285 the University of Cincinnati was first charged with developing a system of shelters for use in limited war operations. Two basic sizes were established: (a) a 16' wide general purpose shelter (personnel shelter) and (b) a 50' x 80' x 25' high aircraft maintenance shelter (hangar).

While the majority of the effort under contract #1285 was exerted on personnel shelters, several hangar concepts were evolved and presented in Volume I of the final report of that contract (Document AFAPL-TR-65-116, dated December 1965). More detailed analysis of these concepts was among the first tasks undertaken in the new contract work.

A summary of several of these previously developed concepts follows:

1. Self-Rigidized Structure

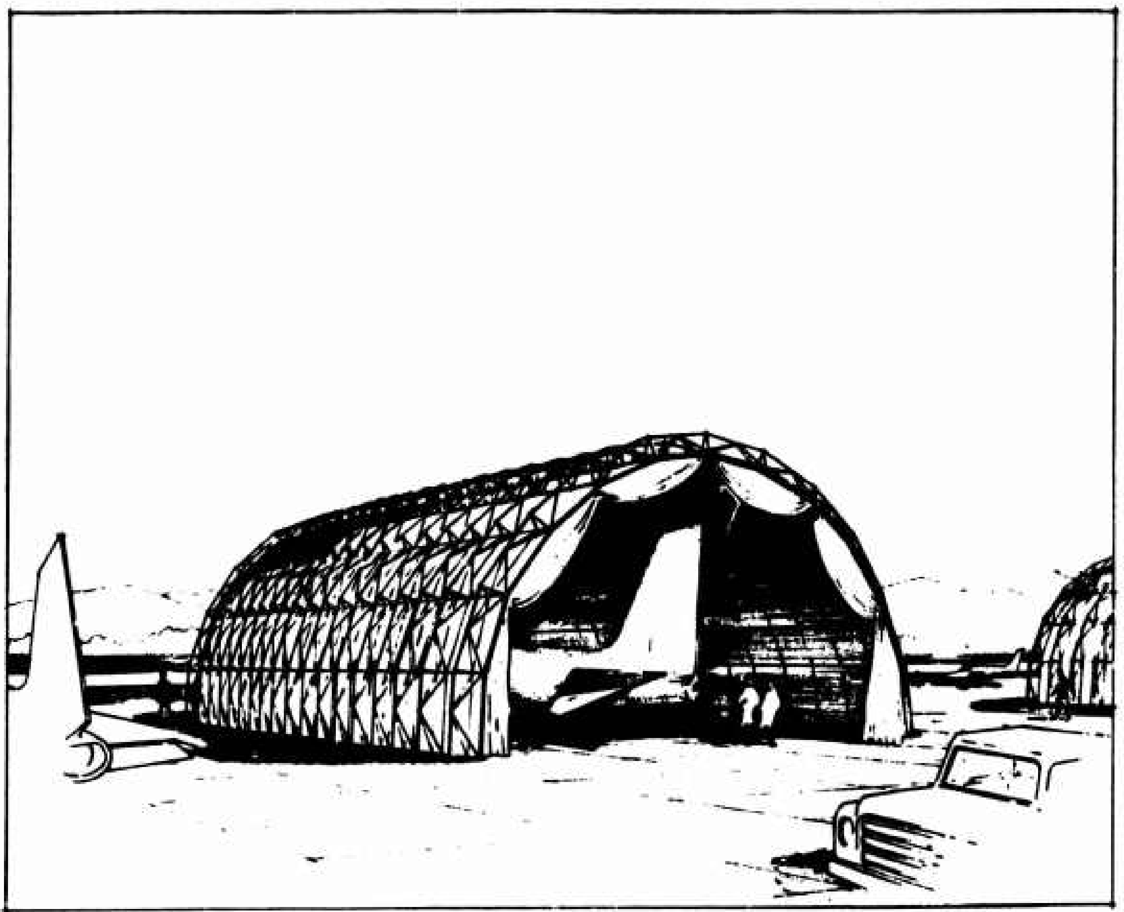
This concept envisioned a fabric shelter supported by integral periodic tubular fabric ribs that would contain encapsulated foam plastic reactants. The addition of heat would energize the reactants and fill the ribs with a rigid foam. It was realized that the state of the art of self-foaming plastics was not sufficiently advanced to make further development feasible at that time.

2. Trapezoidal Rod (or Tube)-Framed Arches (Figure 1)

The basic module of the arch in this concept was a triangular section cage, two planes of which would be trapezoidal shaped trussed frames with the base plane defined by tie rods connecting the short bases of the adjacent trapezoids. The modules could be shipped flat, folded into three-dimensional mode and attached to each other to form arches. A flexible insulated fabric skin was envisioned for the hangar, formed by connecting adjacent arches with purlins and diagonal braces.

3. Arched Beam Concept (Figure 2)

Arch segments of "T" or "I" aluminum sections would be mechanically joined to form arches which would be anchored into grade beams on the ground and spaced with purlins. A double upper flange on the "T" or "I" would form slots into which semi-rigid foam board panels could be slipped and lapped along horizontal seams.



AF 33(615)1285.

Figure 1. Trapezoidal Rod (or Tube) Framed Arch Concept

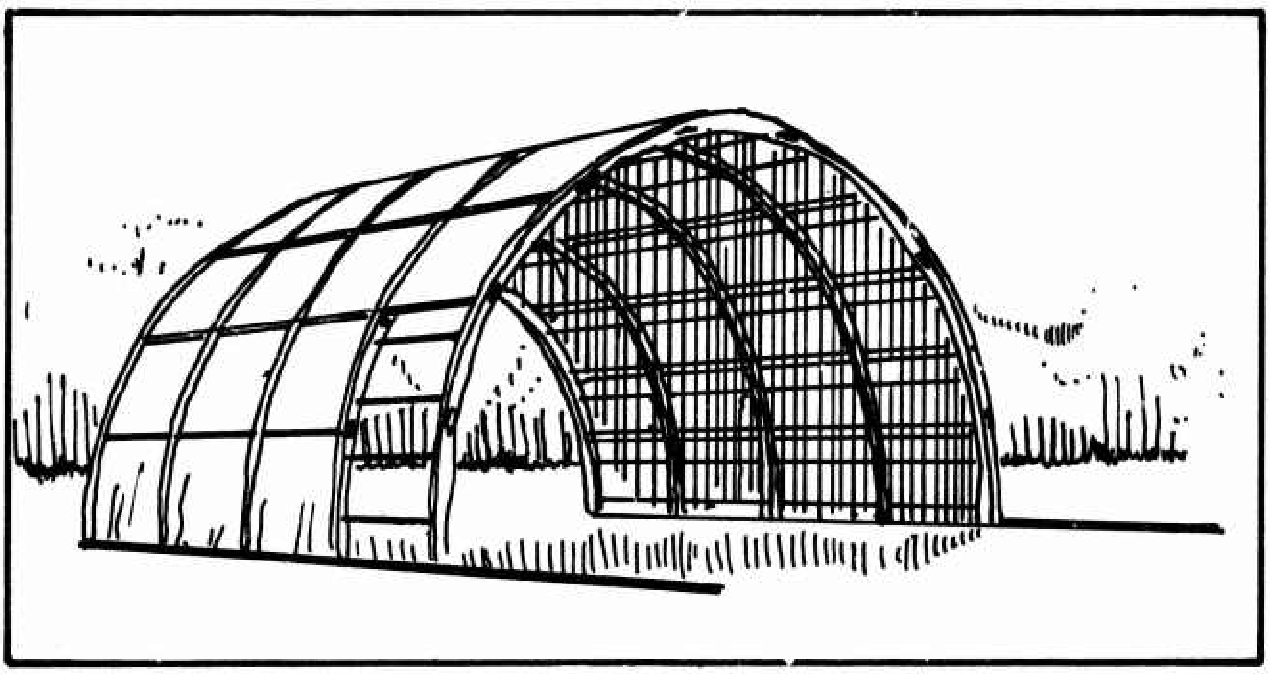


Figure 2. Arch Beam Concept

4. <u>Three-Hinged Arch Concept (Figure 3)</u>

Trusses would be shipped knocked-down,field connected with pins and assembled into three-hinge arches in this concept. Erection would involve anchoring left hinge points to ground, elevating center hinge points, sheathing with fabric or panels attached to adjacent trusses, and then drawing the right hinge points toward the left with cables until the desired elevation would be achieved. Securing the right hinge points to the ground would be the final step.

5. <u>Shell Arch Concept (Figure 4)</u>

Units of a rigid plastic or sheet metal, with some surface modulation for additional stiffness, would be connected together at sides and ends. The units would be assembled on the ground in a horizontal plane. After securing one edge of the assembled group of units to the ground, the other edge would be set in tracks. The two edges would have been tied together with cables. Tension applied to the cables would cause the structure to bow or arch itself into a curved shell.

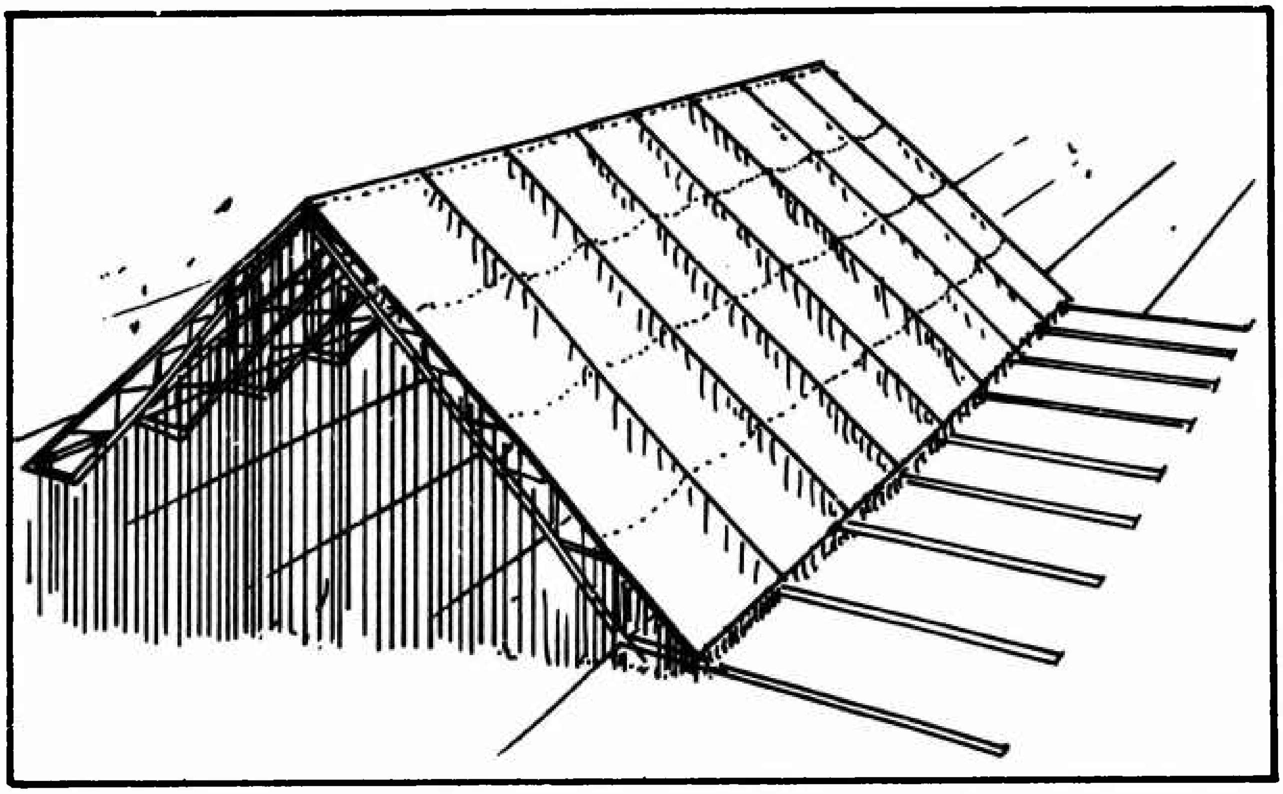


Figure 3. Three-Hinged Arch Concept

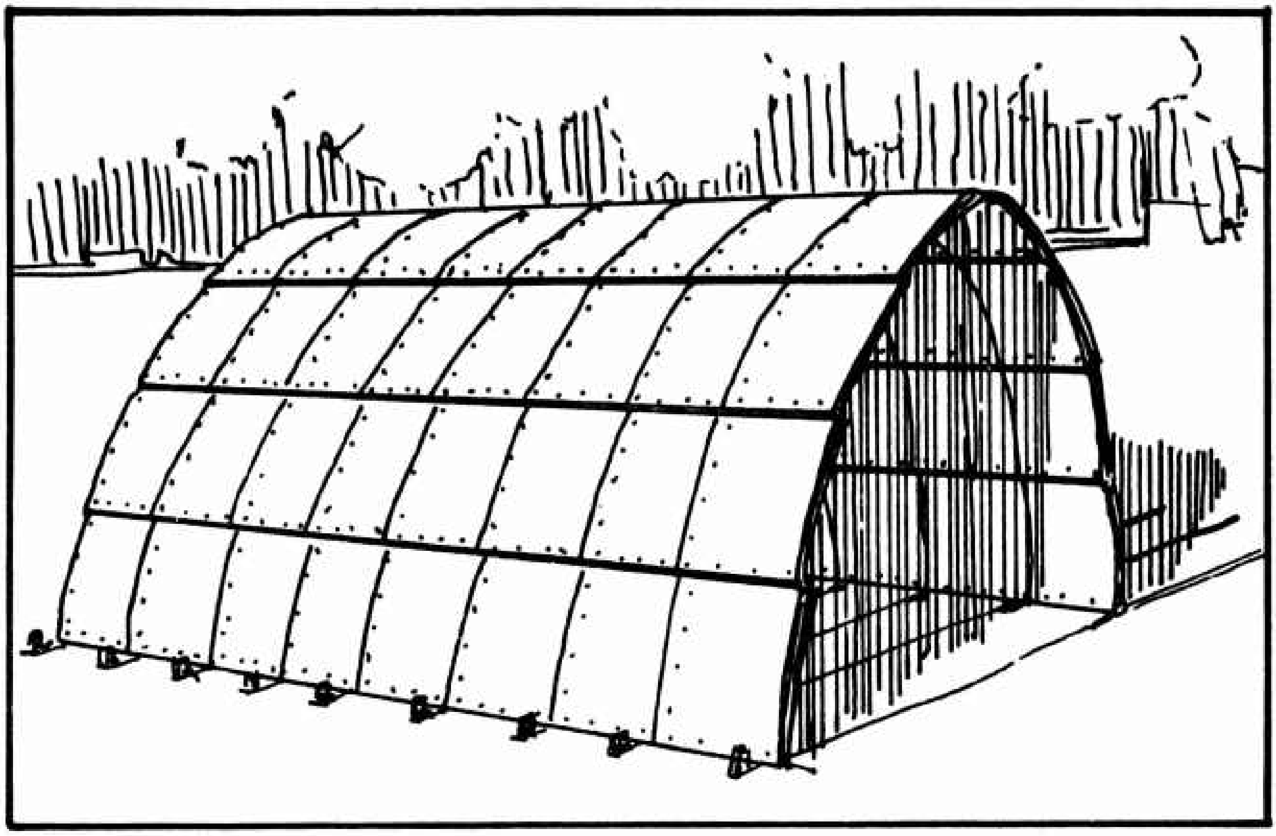


Figure 4. Shell Arch Concept

6. Combination Truss and Panel Arch Concepts (Figure 5)

Rigid panels with interlocking sides and ends would be equipped with "bar-joist" type trusses mounted under the panel. The truss would fold flat against the panel for packaging. The truss would be set upright and joined to trusses of adjoining modules to form a trussed arch with an integral skin.

7. Tension Structures (Figure 6)

One of several tension structures studied involved a fabric suspended by a series of cables from guyed poles located around the exterior perimeter of the shelter. This resulted in a hexagonal shelter. A variation proposed half hex ends on a selected number of rectangular bays.

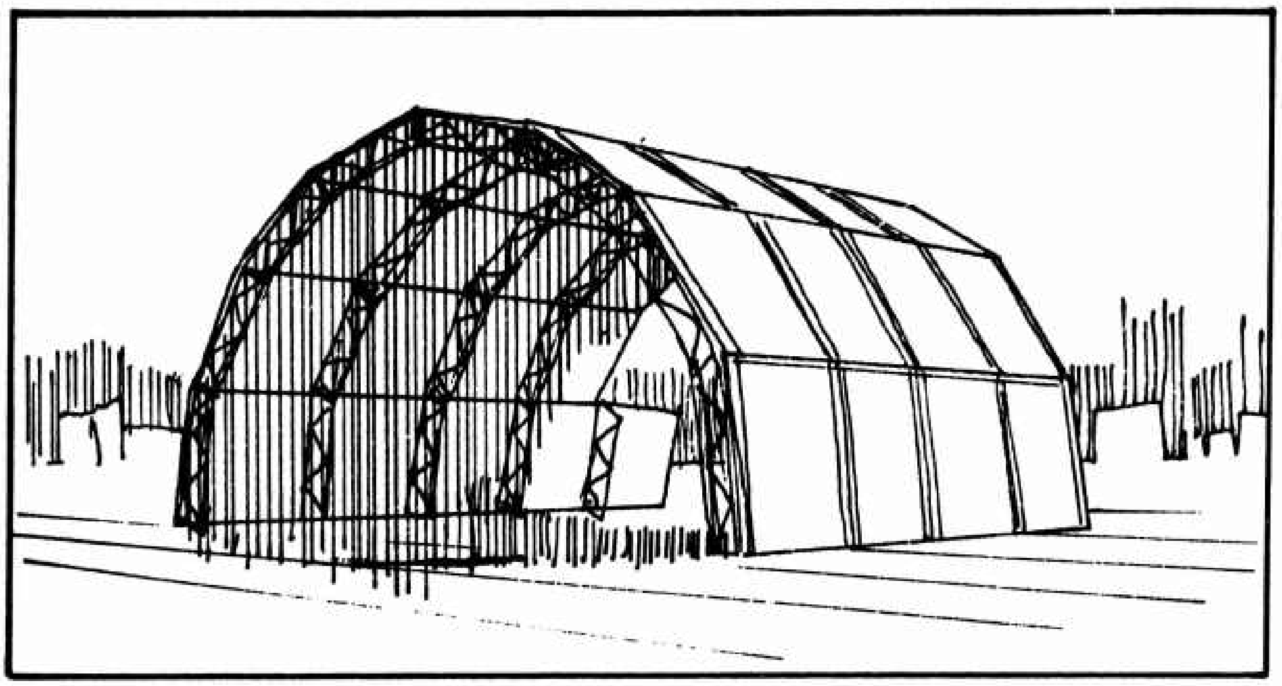


Figure 5. Combination Truss and Panel Arch Concept

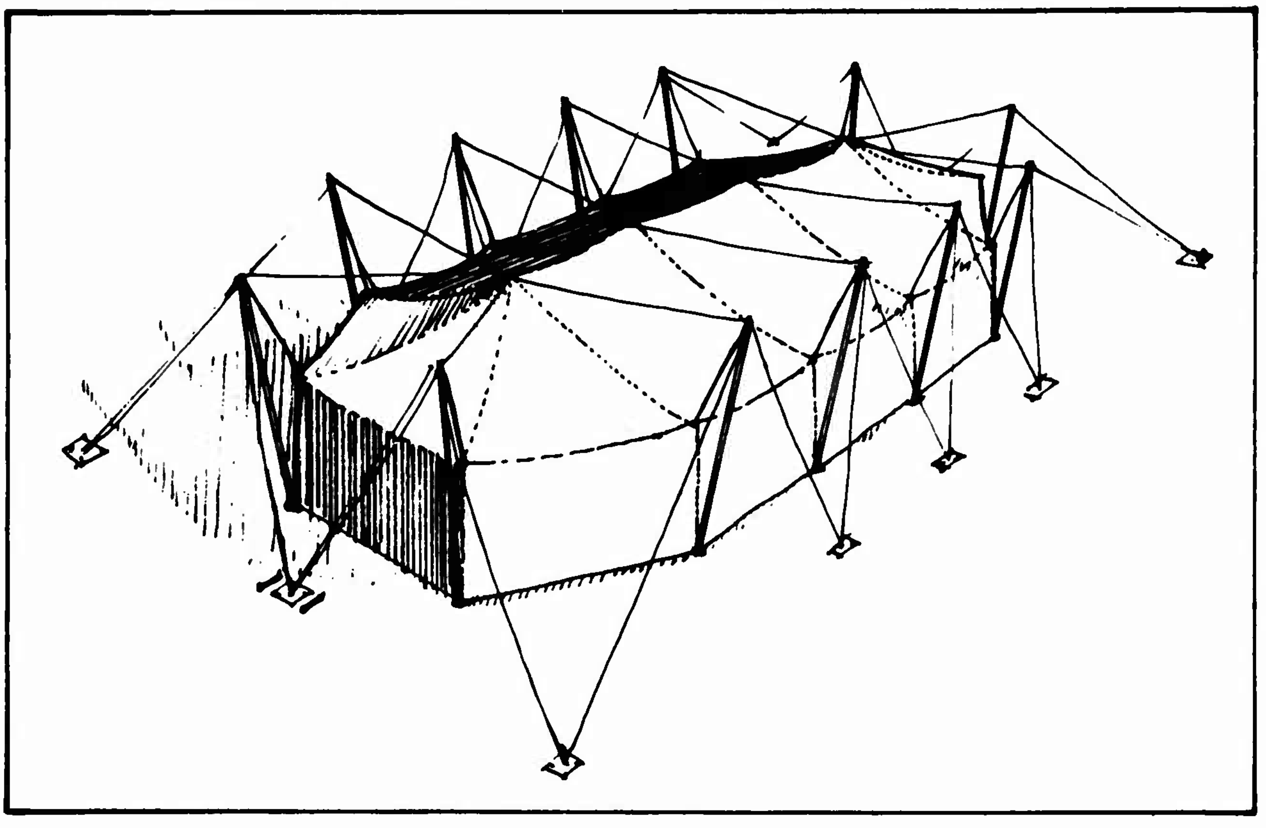


Figure 6. Tension Structure

8. Space Frame Structures (Figure 7)

Interacting tubular framework, in a geometric configuration resulting in a curved plane space frame of barrel vault shape, would be made of short lengths of tubing and pivoting fittings. The space frame would be made up of star shaped subassemblies or modules, connected together by purlins running longitudinally and by lower chord members running transversely across the shelter. Fabric skins or rigid panels would be used to enclose the shelter. End doors of fabric would be suspended from the frame.

9. Composite Plate with Linear Elements (Figure 8)

Rigid flat or curved panels set within formed sheet metal or extruded metal frames would become the primary unit. Units would be interconnected at ground level to form half arches. Two half arches would be pinned together at the midpoint joint and erection would utilize tension cables in a fashion similar to the erection of the Three-Hinged Arch Concept.

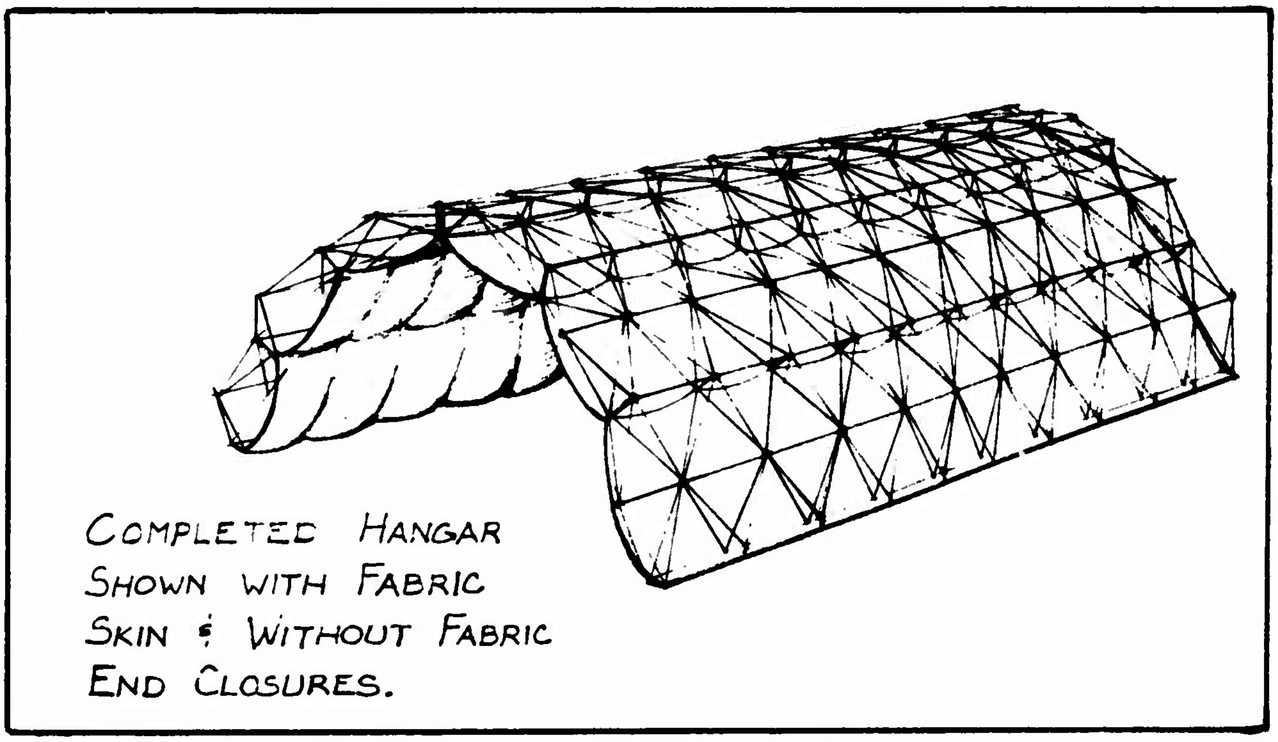


Figure 7. Space Frame Structure

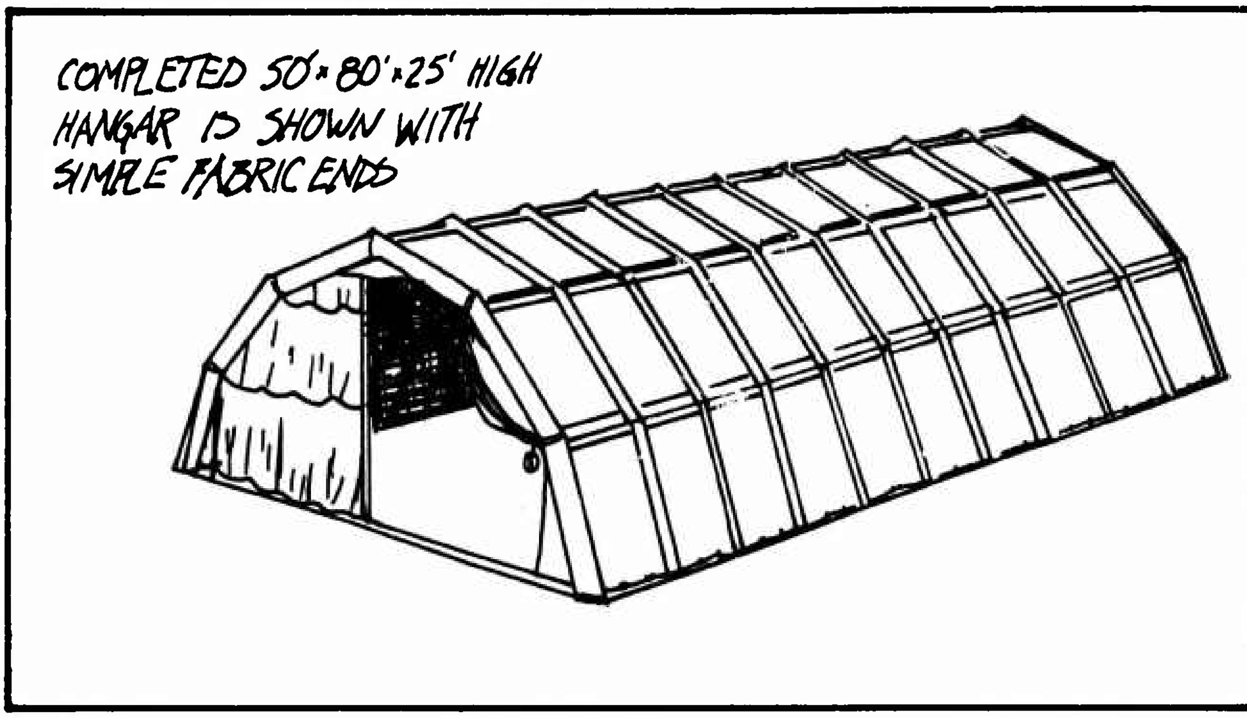


Figure 8. Composite Plate with Linear Elements

B. NEW CONCEPTS PROPOSED

1. Requirements and Goals - Statement of Work

The Statement of Work of Contract AF33(615)3242 specified, in addition to review of earlier concepts derived under the previous contract and reviewed in II,A above, further investigation of two specific concepts:

a. Prefabricated Modular Arch (Space Frame, II,A,8 above)

b. Composite Folded Plate (or shells) and Linear Elements (II,A,9 above)

Governing all concepts to be generated were certain physical requirements and design goals; these are summarized below:

a. Physical Requirements

Dimensions: 50' x 80' floor plan with a 25' center height

Doors: Full width and height, flap or accordion at each end

Foundation Beam: Prefabricated lightweight grade beam to provide a level foundation over uneven ground

Tension Ties: Flat web ties can be utilized to take tension loads caused by arch construction

Connectors: Simple pin type, snap, or "Velcro" fabric zipper

Anchorage: Adequate tie downs and stake tabs for anchoring structure to the terrain

Insulation: Reflective type for fabric covered concepts, "Foam" or "bat" type for panel covered structures.

Color: Olive drab or camouflage

b. Design Goals

Package Weight: 7500 pounds

Package Cube: 800 cubic feet

Operational Life: 15 years shelf life, 3 years operational life

Cost: $25,000 or less per shelter in quantities of 50 units

Erection Time: 50 man-hours or less

Loads: 90 mph wind at 30 ft. and 10 psf on roof areas

Approximately two months after effective date of contract, four distinct concepts were presented to the project engineers. They represented, on one hand, a distillation and refinement of earlier concepts, and, on the other hand, entirely new concepts. They were presented in drawing and small scale model form as Concepts A, B, C and D.

2. Four Concepts Presented December, 1965

a. Concept "A"

Concept "A" was a further development of the Three-Hinged Arch Concept presented in the earlier contract. Figure 9 illustrates a partly erected hangar. Its erection procedure was described on page 5.

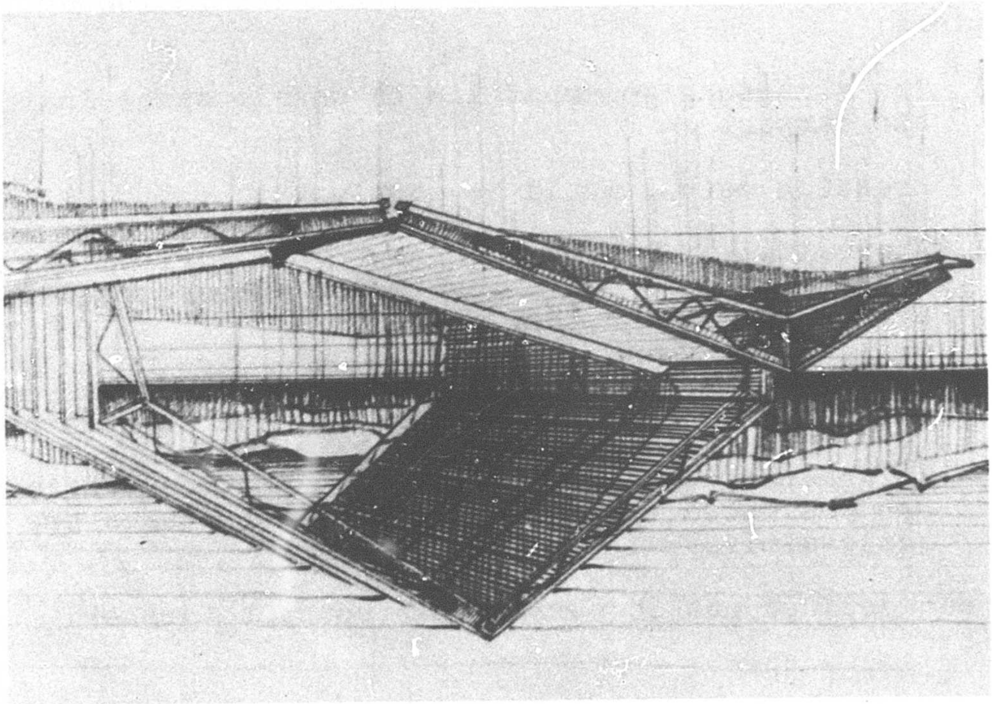


Figure 9. Concept "A" (Three-Hinged Arch)

The structural bents that would be hinged together to form the arches were designed in truss forms with sections approximately 8' in length. Two-inch square 6061-T6 aluminum tubing was specified for the trusses. Purlins would be eight feet in length and spaced four feet on center. They would be made of the same two inch square tubing as specified for the trusses.

Corrugated aluminum sheet was proposed as the skin panel material. Weathersealing between adjacent bays could be accomplished with a fabric and draw cable device similar in principle to that utilized in the Jamesway shelters:

Weights were calculated as follows:

Trusses:	4000#
Purlins:	1600#
Sheeting:	3200#
Total	8800# plus end closures, counterflashing and assorted fittings.

Critical review of Concept "A" evoked the following observations:

(1) The structure somewhat limits usable space inside the hangar.

(2) Erection method would be complex.

(3) Approximately 16 truss segments, 18 purlins and 8 sheeting panels would have to be subassembled for each arch section (bay).

(4) Configuration of hangar section would require more surface material than would a semi-circular arch.

(5) In general, the approach was the most conventional one presented. Several existing structures are quite similar.

It was decided not to pursue this concept further.

b. Concept "B"

This concept (illustrated in Figure 10) combined features of the original Space Frame structure and the Composite Plate with Linear Elements concept and as such represented the further investigation of these two concepts called for in the Statement of Work.

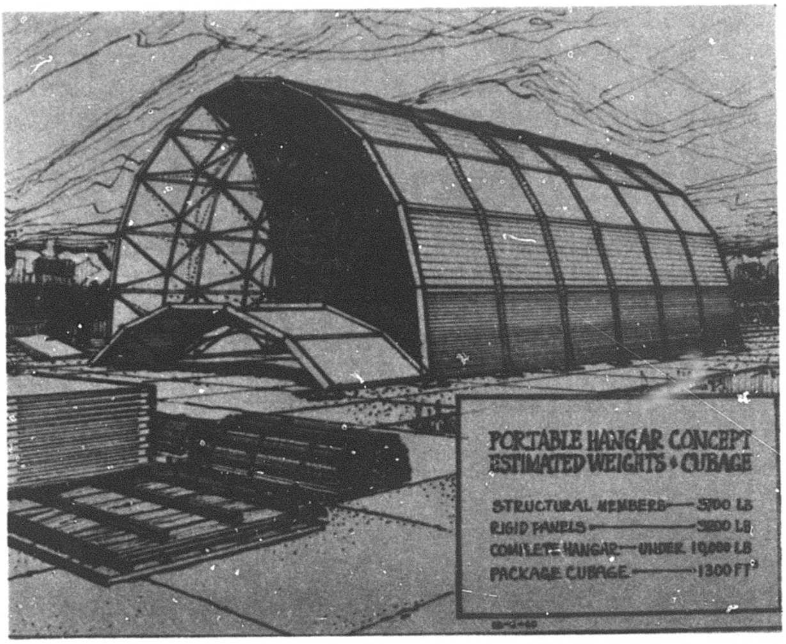


Figure 10. Concept "B" (Space Frame and Panels)

The earlier space frame concept utilized three dimensional star shaped modules assembled from tubes and fittings. Purlins parallel to the axis of the shelter rigidized the folding modules in their x-shaped mode. This created a pyramidal shaped cage which, when joined along hinge lines provided by the lower set of purlins, formed a connected strip of modules. These were converted into an arch by tying modules to each other at their midpoints with tension chords of a length that would cause the modules to triangulate and define the proper angles between the arch segments. (See Figure 11) In this concept a fabric skin would have to be suspended from the chords of the arches after the arches were erected with a hangar.

Concept "B" resembles the earlier space frame in some respects. The major difference is that a rigid panel replaces a plane implied by the purlins and chords of the earlier concept in that the pyramids have their points downward rather than pointed upward. Chords connecting the points of the pyramids then join the modules and define the angles between the hinged modules. The advantages over the earlier space frame concept were: 1.) the skin was made up of rigid panels rather than fabric, 2.) the skin was the exterior surface of the hangar

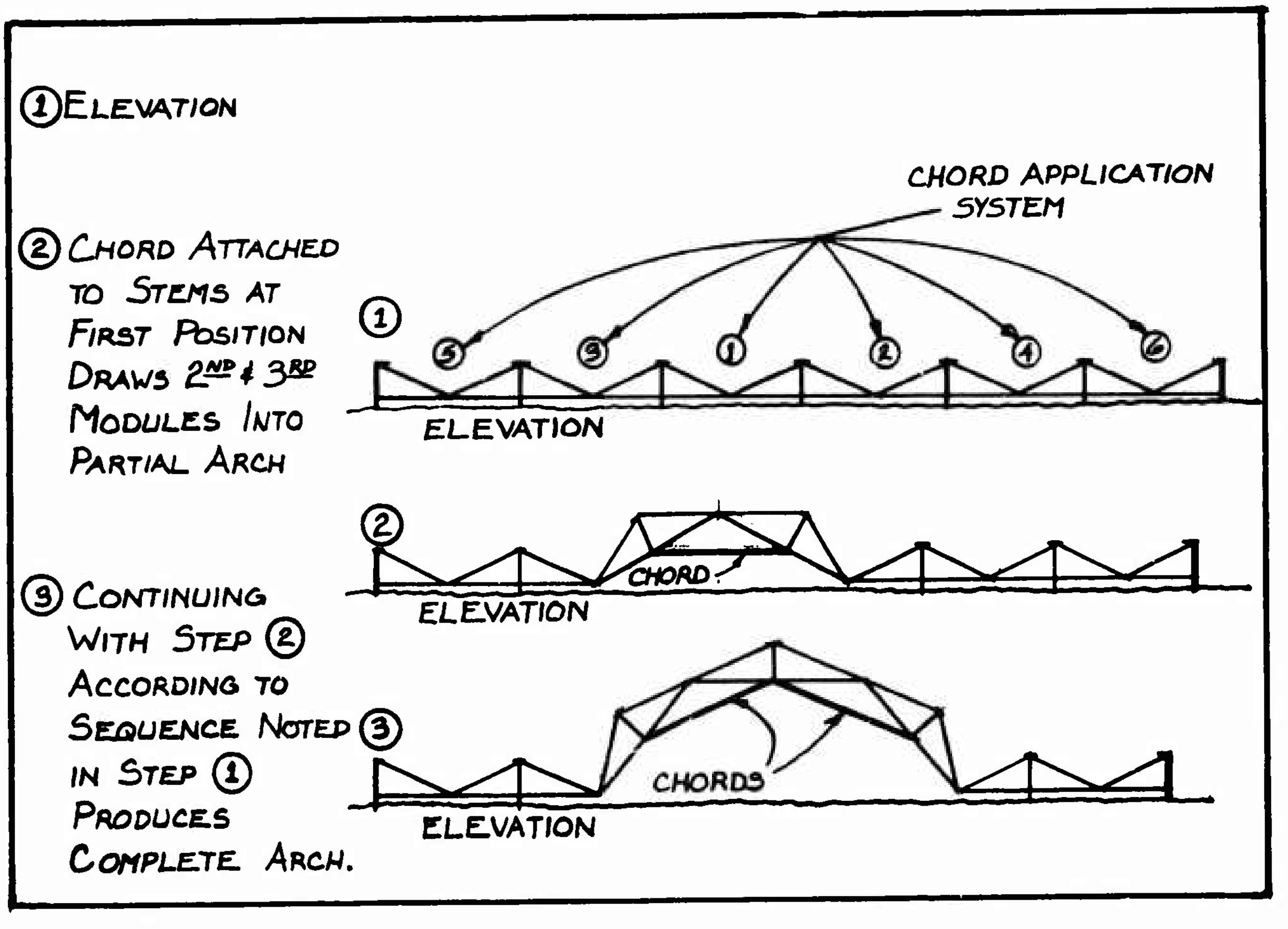


Figure 11. Erection Sequence, Earlier Space Frame Concept

rather than being suspended under a frame exposed to the weather and 3.) erection of skin and frame occurred simultaneously rather than in two separate sequences of operations. (See Figure 12) A "Jamesway" type sealing of vertical joints between arches was envisioned.

Critical review of Concept "B" evoked the following observations:

(1) Cost of panels would be high due to structural requirements and molded-in fasteners to receive frame members.

(2) Frame and connector special fabrication would involve high cost.

(3) Erection time would be lengthened by high number of fastenings to be made.

(4) Sealing of horizontal and vertical joints might cause problems.

It was decided that no further work on Concept "B" would be undertaken.

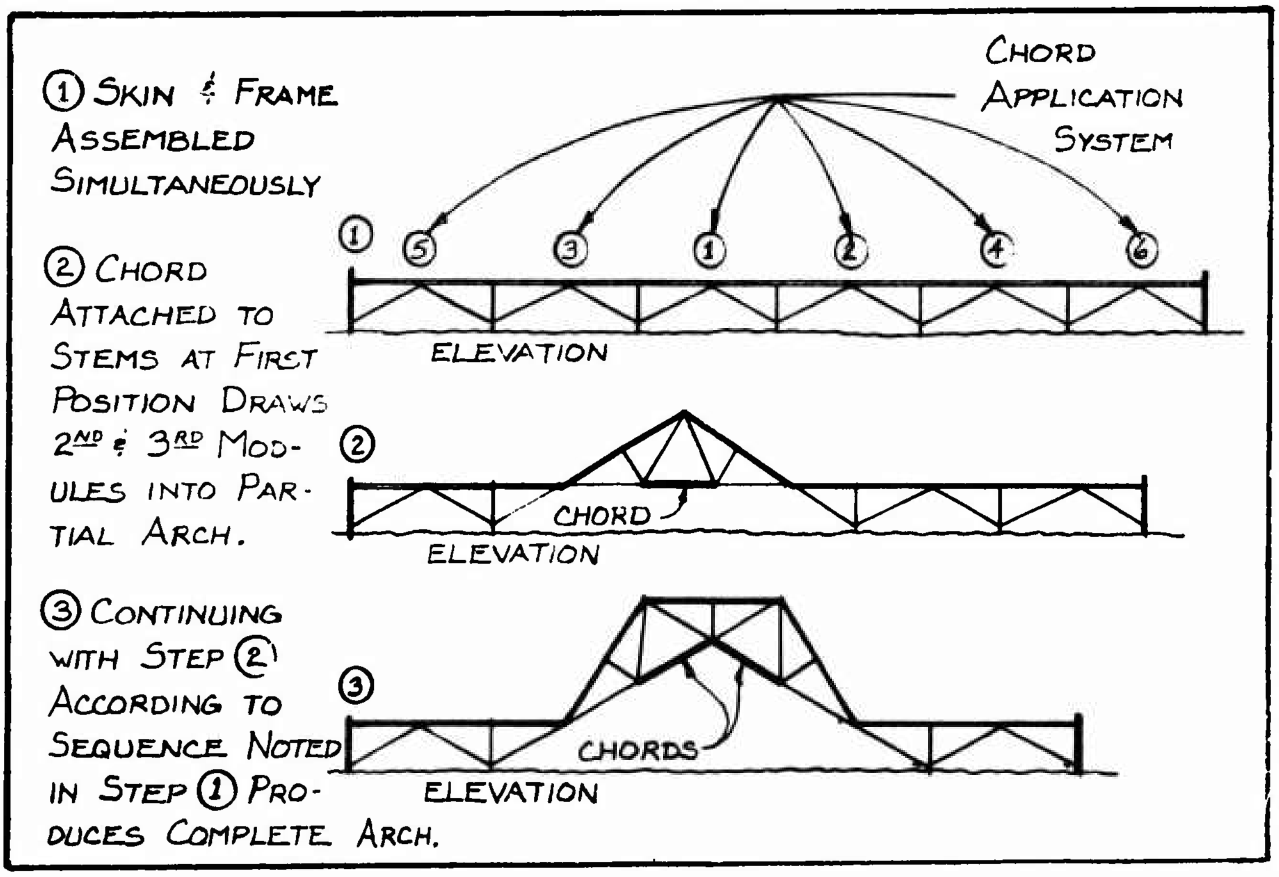


Figure 12. Erection Sequence, Concept "B"

c. Concept "C"

This concept was unlike any previously submitted and utilized tipped-up aluminum arches and fabric skins. (See Figure 13) As this was one of the two concepts selected for further study prior to a presentation to Headquarters, Tactical Air Command, detailed description of the concept will be deferred to the next section of this report (II,B,3a).

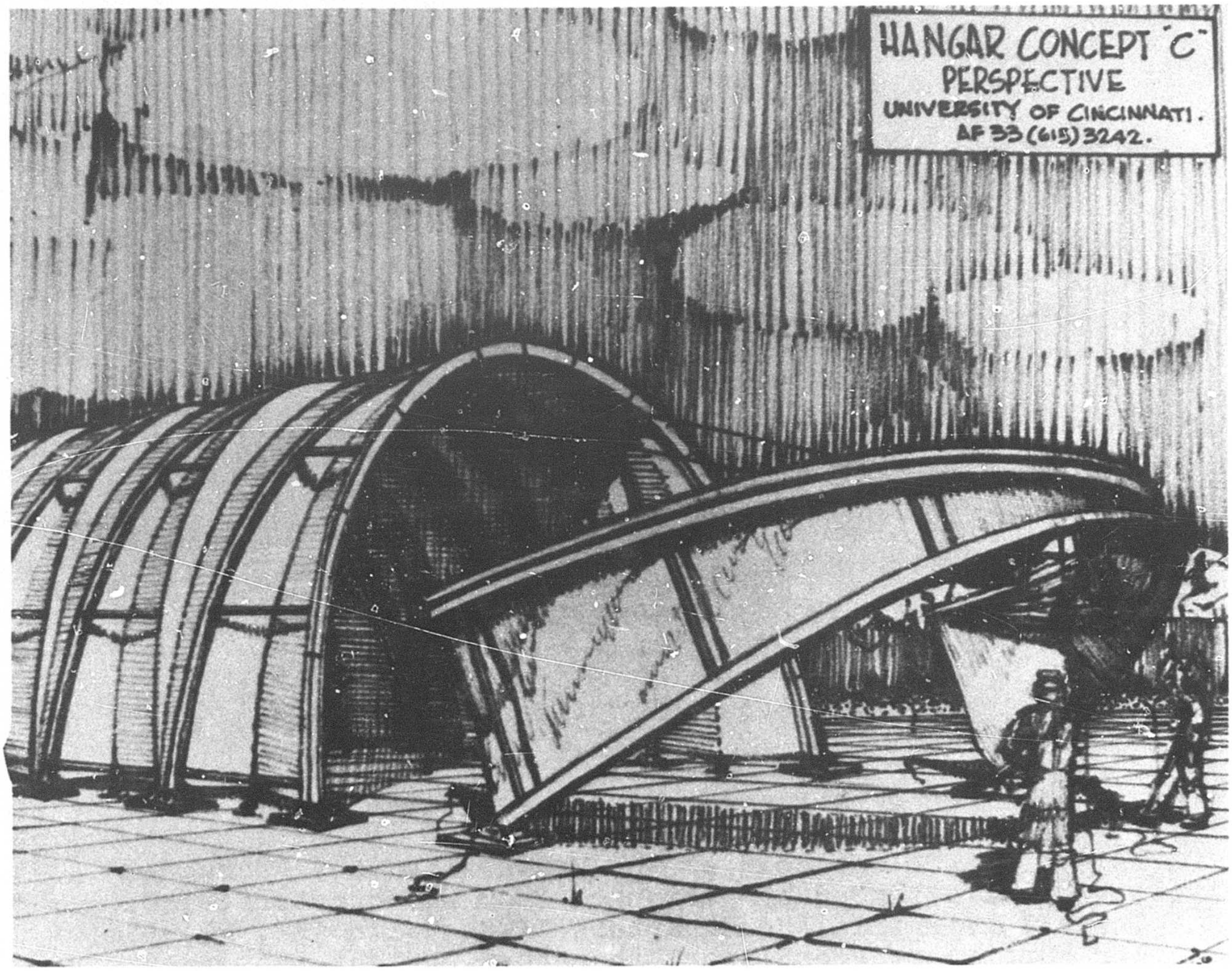


Figure 13. Concept "C" (Tip-Up Arch and Fabric)

d. Concept "D"

Concept "D" (Figure 14) was conceived as a shell type shelter and utilized a double-curvature module of sandwich construction. This was the second concept selected at the December 1965 review for further study. To avoid redundancy, detailed discussion of this concept will also be deferred to the next section of this report.

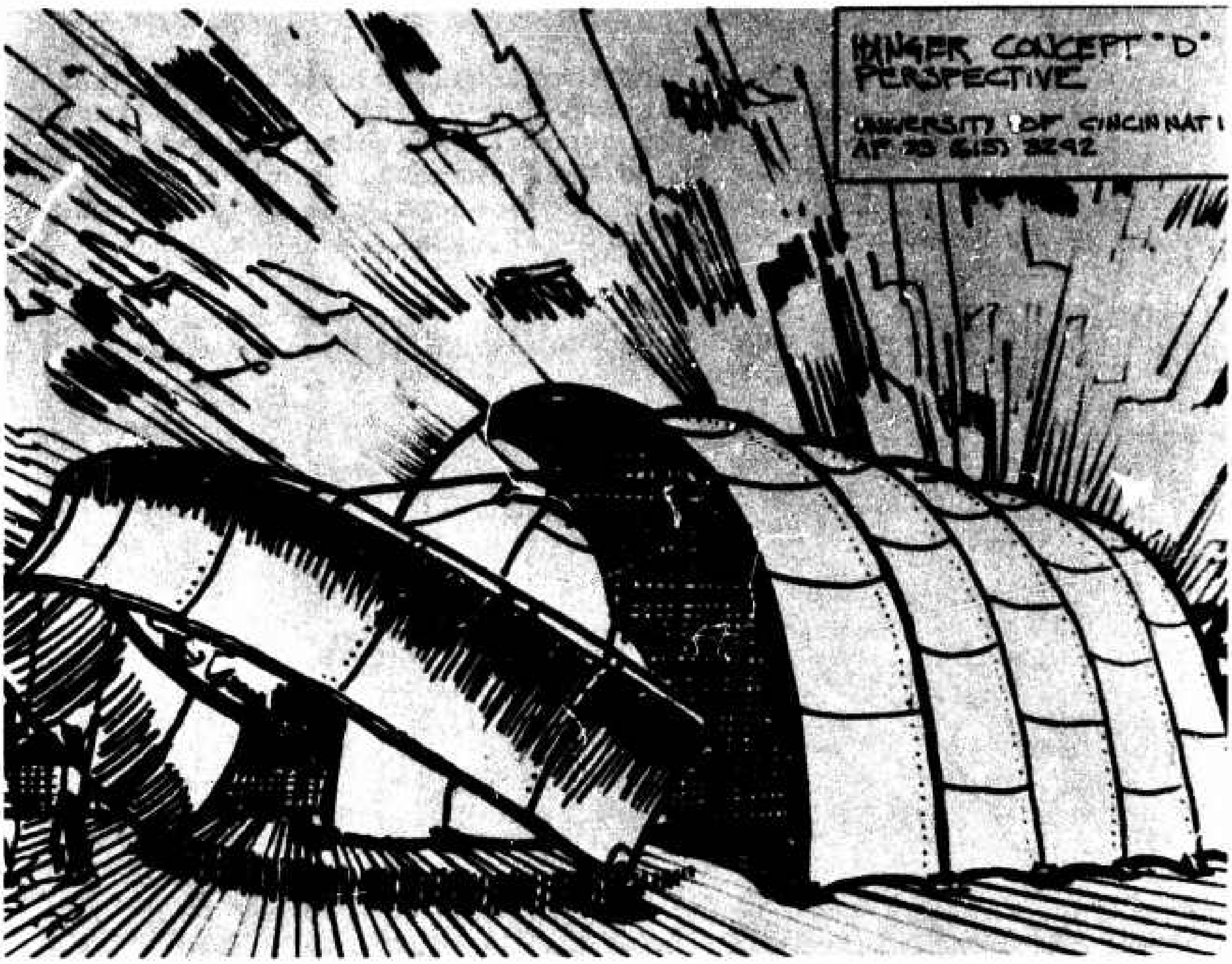


Figure 14. Concept "D" (Double Curvature)

3. Two Concepts Presented February, 1966

A conference was held at the University on 9 February 1966. It was attended by personnel from Headquarters, TAC, Langley AFB, Virginia; Headquarters TAWC, Eglin AFB, Florida; and Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio.

Concepts "A" and "B" were reviewed briefly and Concepts "C" and "D" presented in greater detail.

a. Concept "C"

The appearance of a hangar based on Concept "C" remained essentially unchanged from the previous presentation. (See Figure 13) Figures 15 through 23 were utilized at the February meeting. They deal with various aspects of the concept and are presented in the same order as the following discussion of the same aspects.

Basis of Concept (Figure 15). The basic structural concept involves adjacent segmented aluminum arches that are, in erected mode, eight feet apart at their bases and touching each other at their highest points. Arches are of two types: 1.) "full" arch (meaning an "I" section) and 2.) a "half" arch (meaning a "channel section" of half the width of the "I" section). Half arches are hinged at the base and high point of a full arch to form a basic unit. The arches' span is 50' and the height at center point is 25'. Ten spread units give the required 80' length for the hangar.

Erection Methods (Figure 16). Arch units are assembled on the ground, and the base of one half arch is hinged to previously anchored base plates. Spreader tubes are inserted between the half arch on the ground and the full arch. The entire assembled unit is then lifted to a height that allows other erection crew members to pull the unit into upright position. Gaff hooks are used to assist in the lifting operation. The base of the full arch is locked into the next set of previously anchored base plates, and the remaining half arch is tilted out to its final angle of repose (parallel to the first half arch). These steps are repeated for each unit resulting in a frame with successive leaning arches consisting of alternate "I" sections and double back-to-back channel sections. Fabric skins are attached to each unit prior to lifting up into upright position.

Hinge Details (Figure 17). The hinges at the base plate and at the highest point of the adjacent arch are diagrammed and discussed on this plate. Removable self locking hinge pins with ring grips and retainer cables would be used throughout.

Base Plate Details (Figure 18). Fabricated steel or aluminum base plates are illustrated. These provide for hinging of one half arch, securely seating and locking into place the remaining hinged full and half arch assembly, and securing of draw ropes used to keep fabric panels taut.

Fabric Skin Details (Figure 19). Lightweight waterproofed fabric skins are cut in two patterns: one with long edges cut in concave and the other in convex configuration. Metal hooks at the edge hems of the fabric are engaged in predrilled holes in the flanges of the arches. The details of a spring steel bracket device used on the flashing flap that seals one arch unit to the adjacent unit are shown. Draw ropes are utilized here to hold the flashing taut as well as at the valleys of the fabric panels.

Miscellaneous Details (Figure 20). Details shown here include spreader tubes for separating arches in erected mode, splice plates for connecting arch segments to each other, gaff hooks and pulley assemblies for use in erection.

End Wall Door (Figure 21). A concept for a droppable fabric end wall is presented. Raising and lowering of the fabric is accomplished by a system of nylon ropes and pulleys. A zippered flap in the fabric end wall can serve as a truck door (when rolled up and tied) and as a personnel door (when one corner is raised and tied back).

Packaging (Figure 22). One 463L pallet would store two arch units plus an appropriate portion of fabric and accessory items. Each packaged pallet would weigh approximately 2460 pounds (exclusive of the pallet weight) and would cube at approximately 230 cubic feet. Each hangar would require five pallets resulting in a net weight of 12,300 pounds and net cubage of 1150 cubic feet.

Weights (Figure 23). Alternate aluminum and magnesium structural sections are presented for use in the arches, and resulting weights are tabulated. Weights of fabric and accessory metal parts are estimated and show a total of 1900 pounds per hangar.

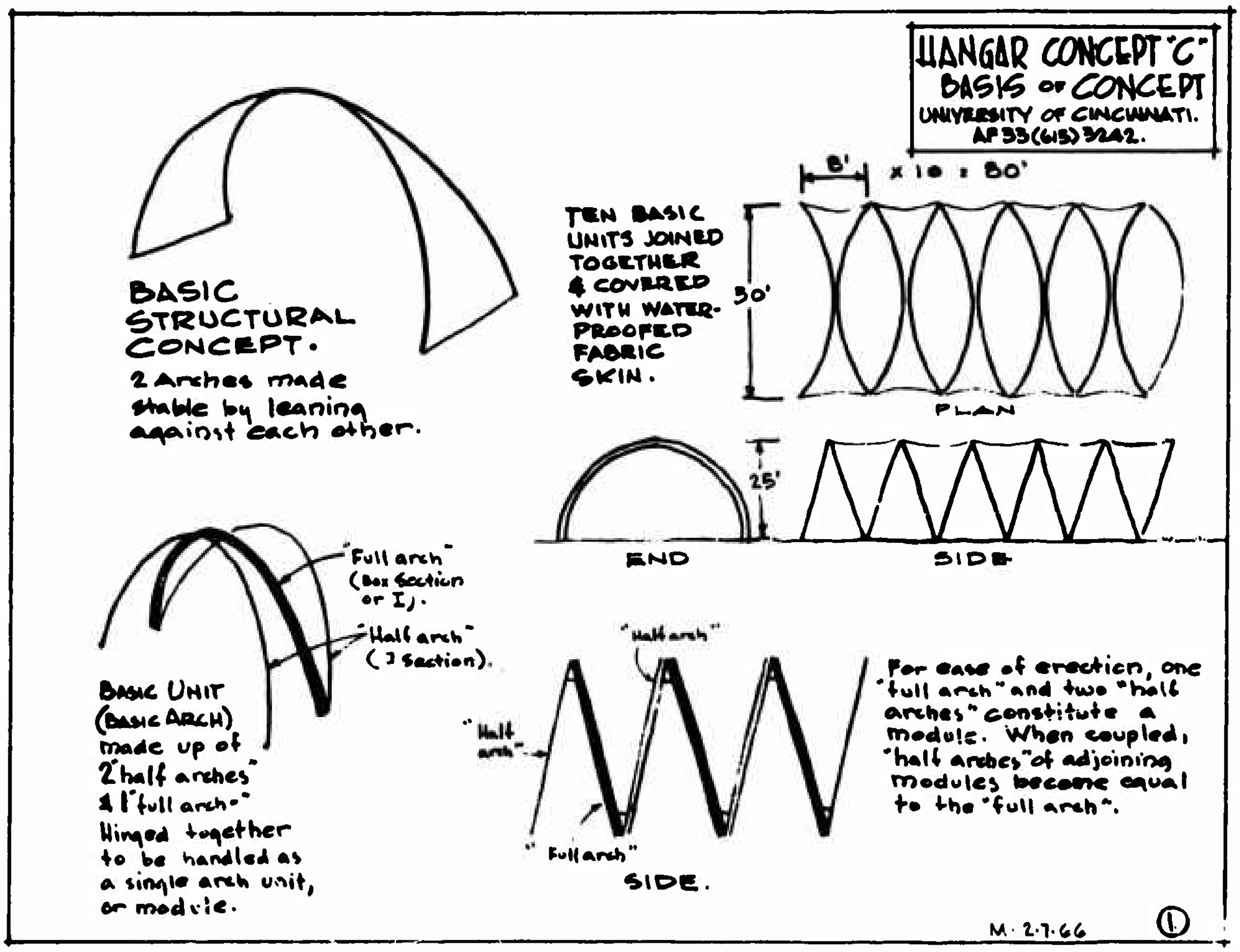


Figure 15. Concept "C" - Basis of Concept

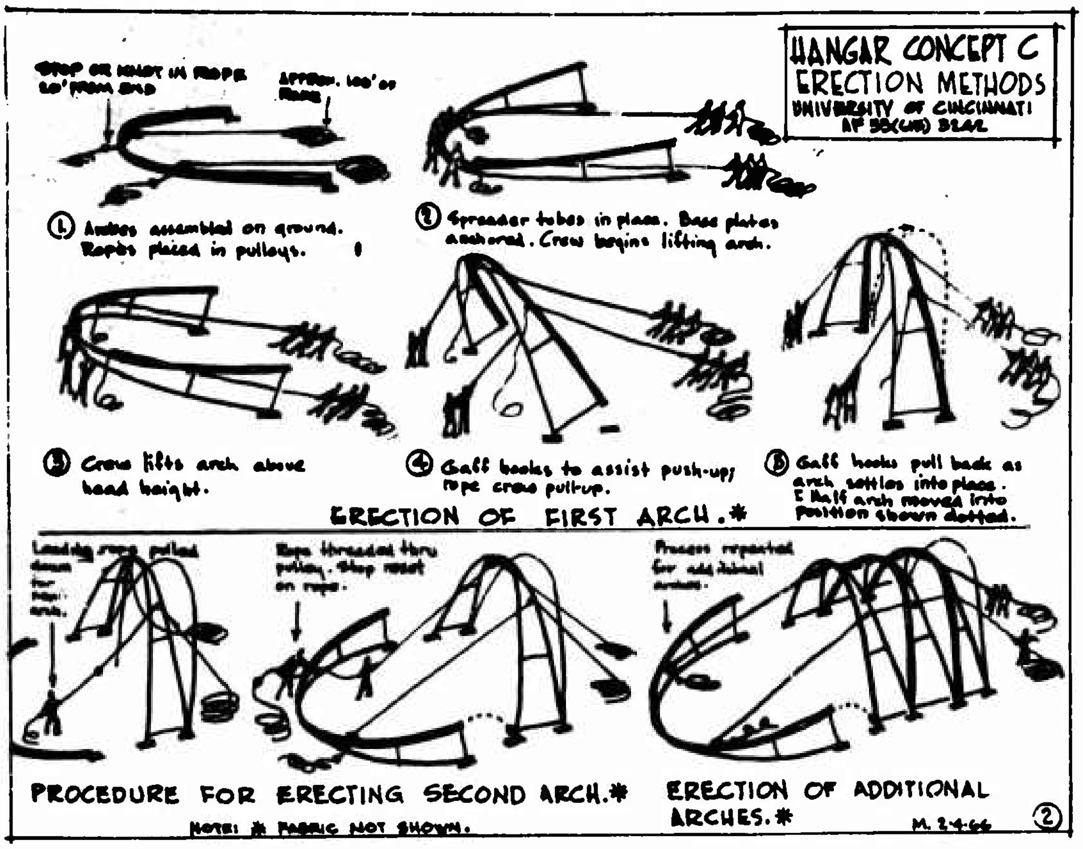


Figure 16. Concept "C" Erection Methods

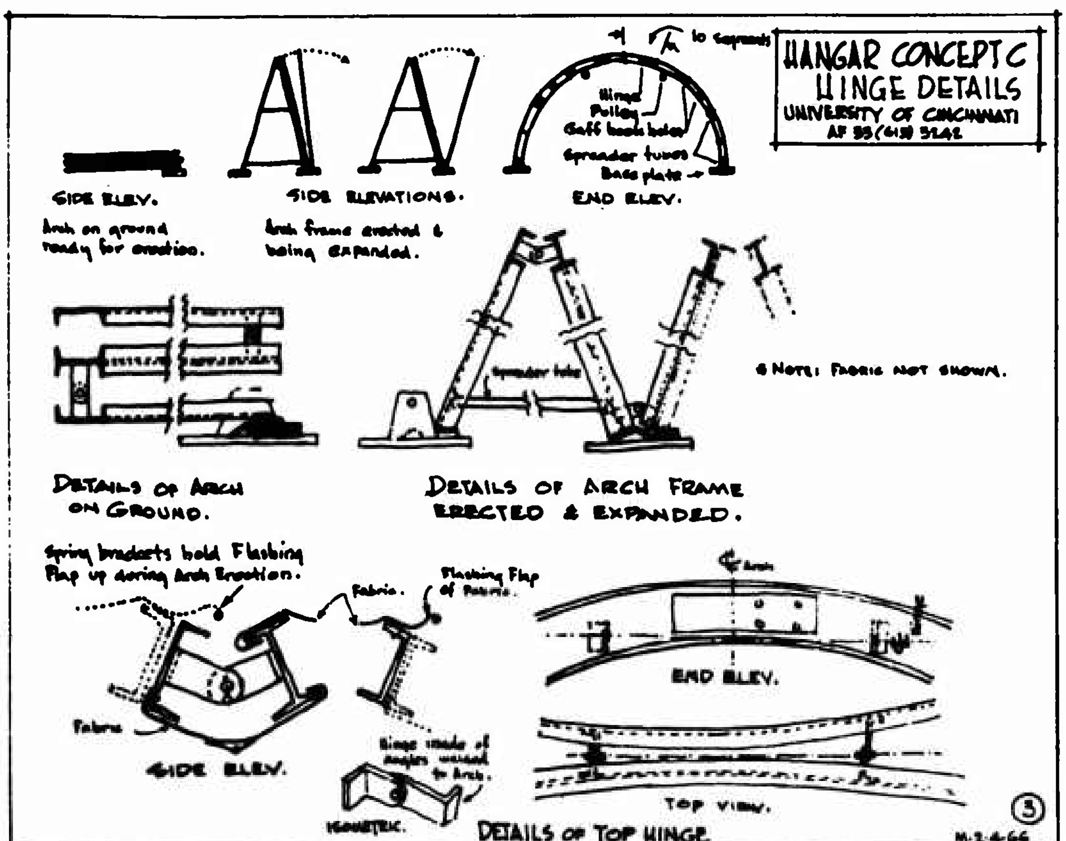


Figure 17. Concept "C" Hinge Details

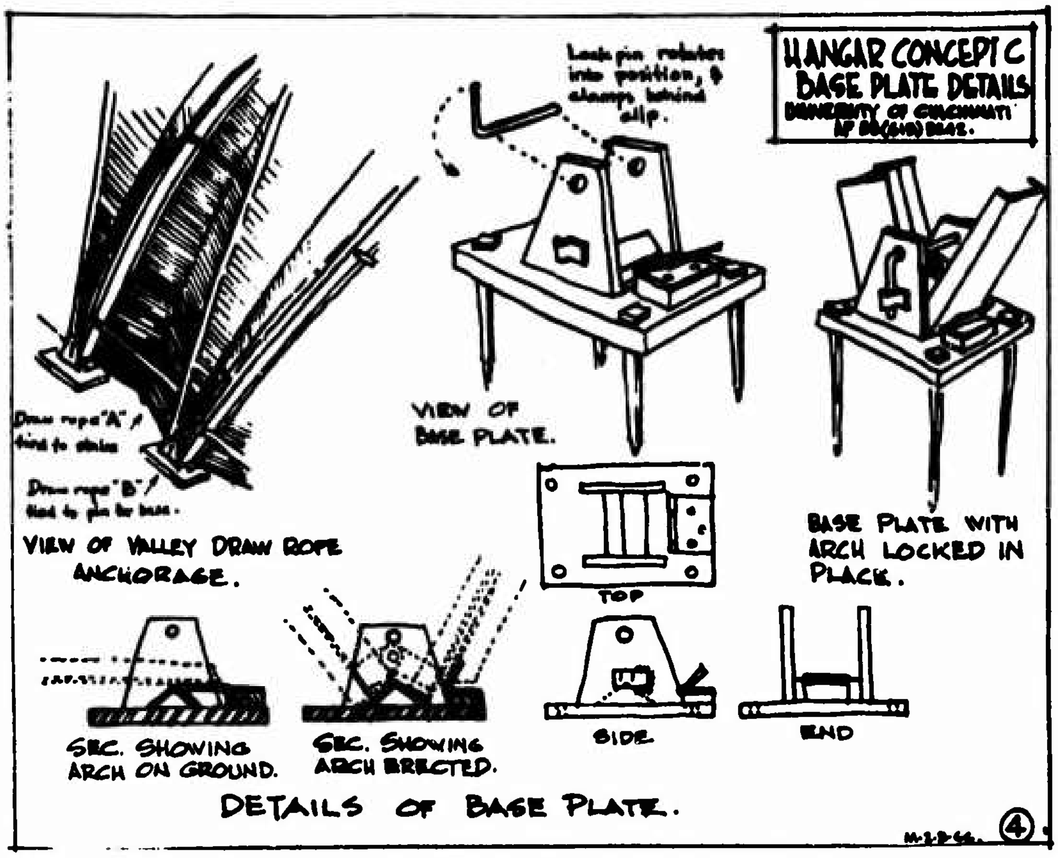


Figure 18. Concept "C" Base Plate Details

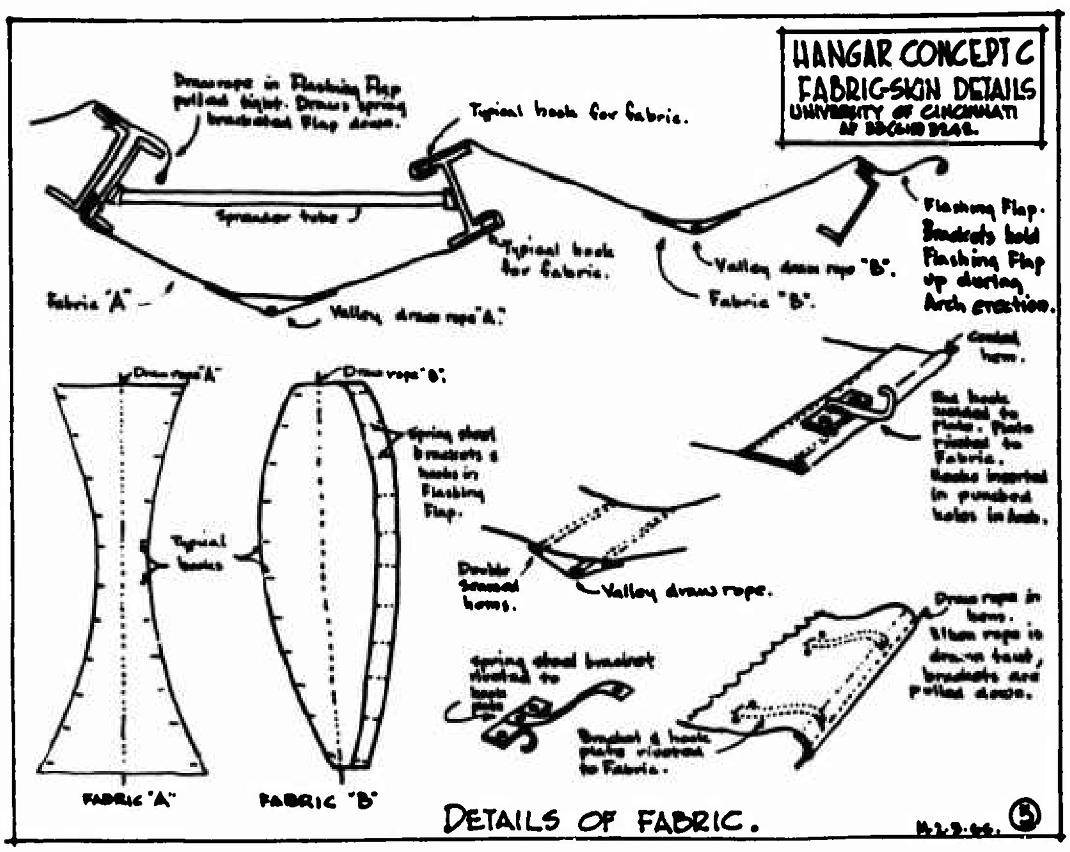


Figure 19. Concept "C" Fabric Skin Details

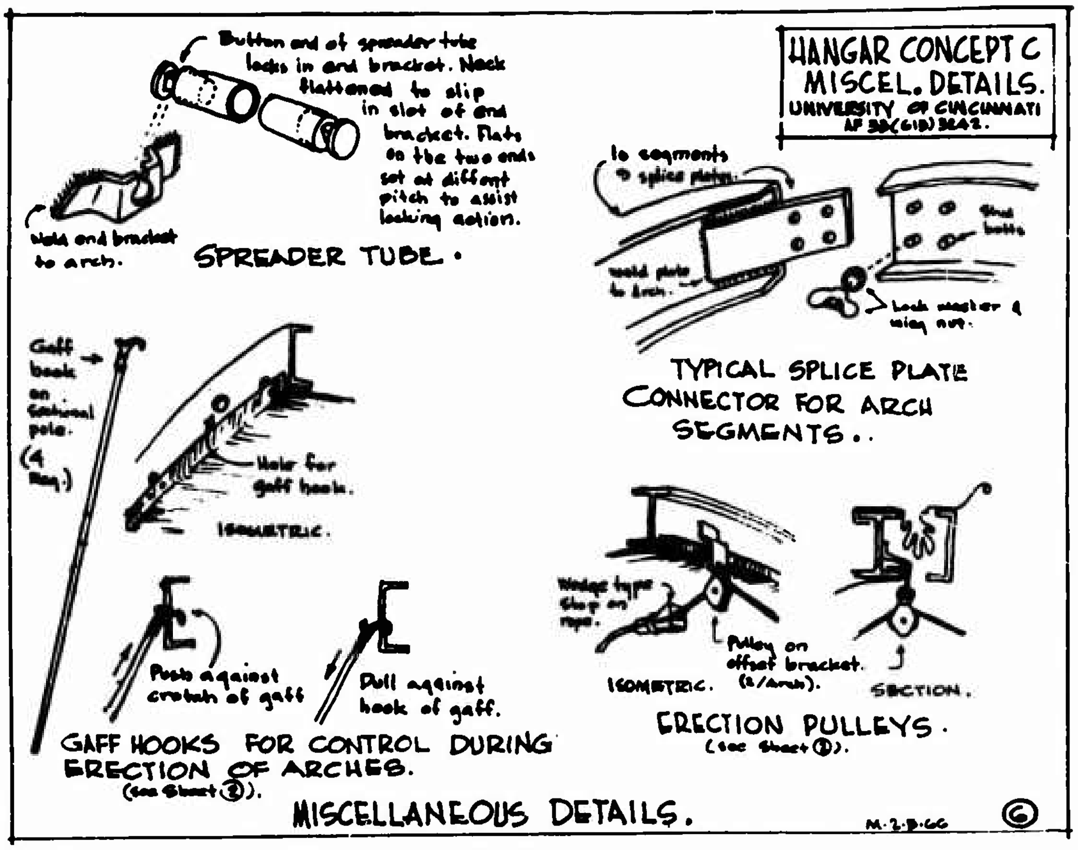


Figure 20. Concept "C" Miscellaneous Details

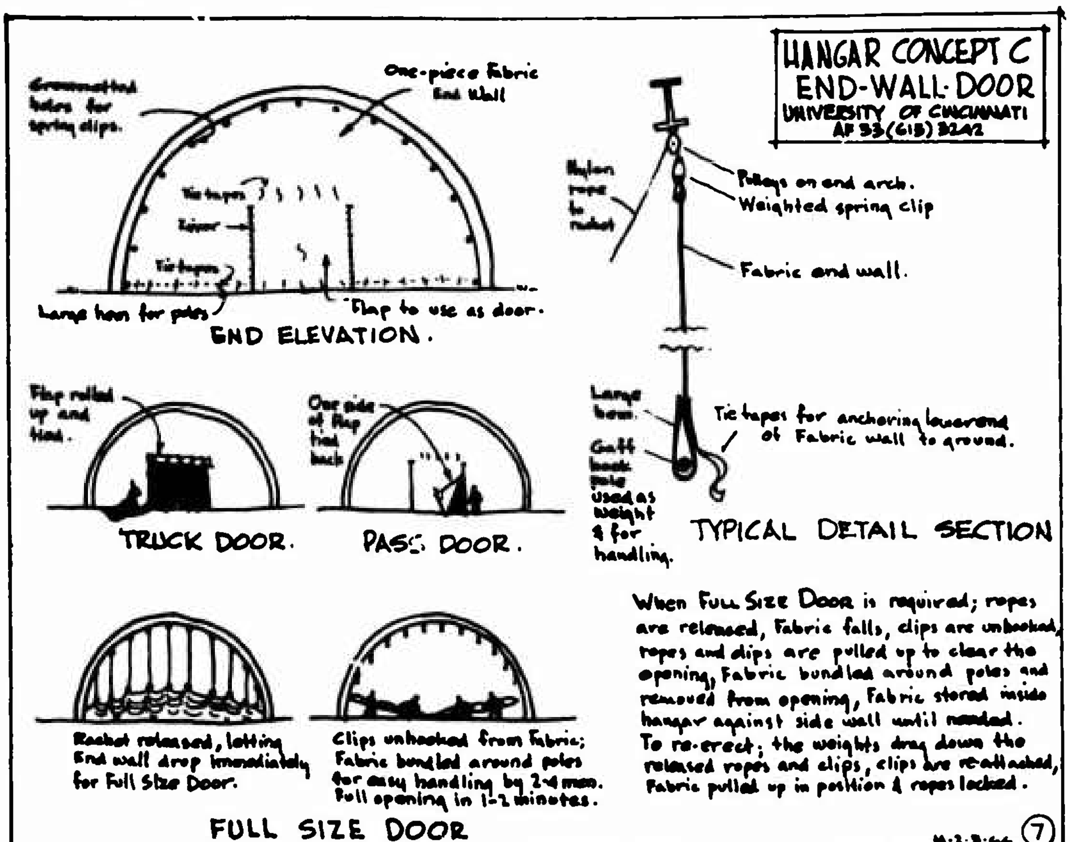


Figure 21. Concept "C" End Wall Door

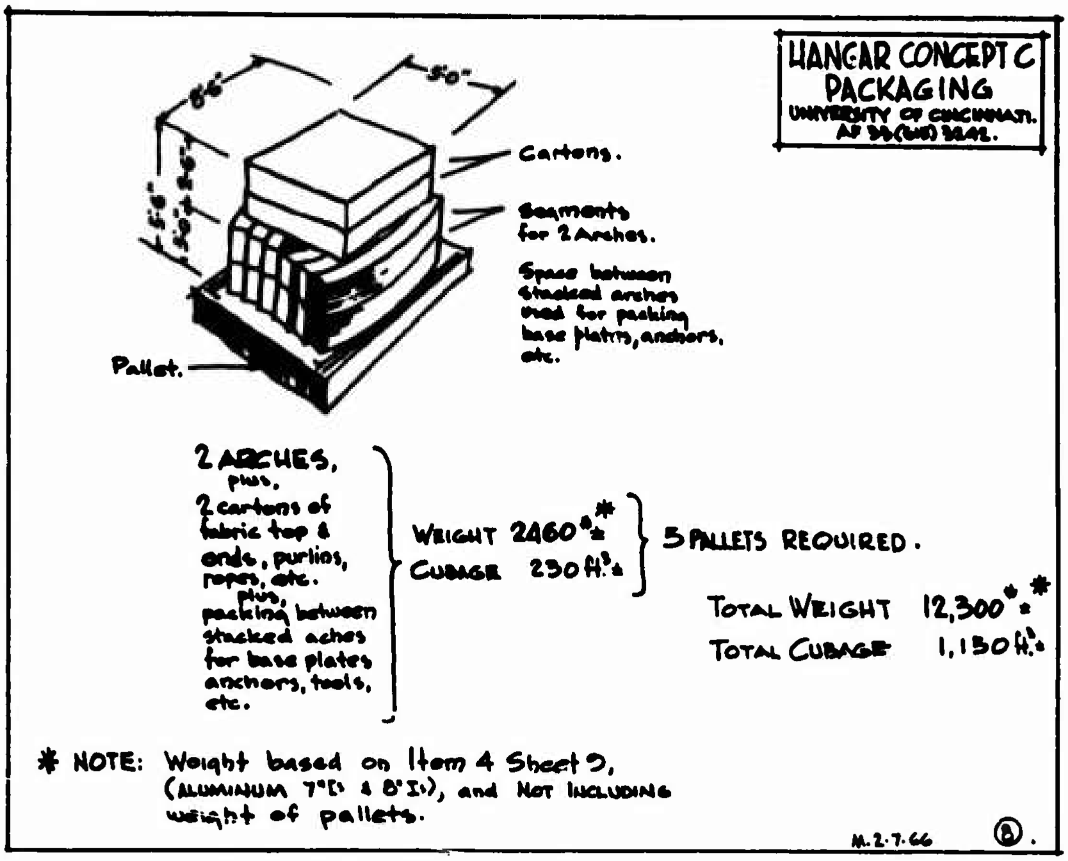


Figure 22. Concept "C" Packaging

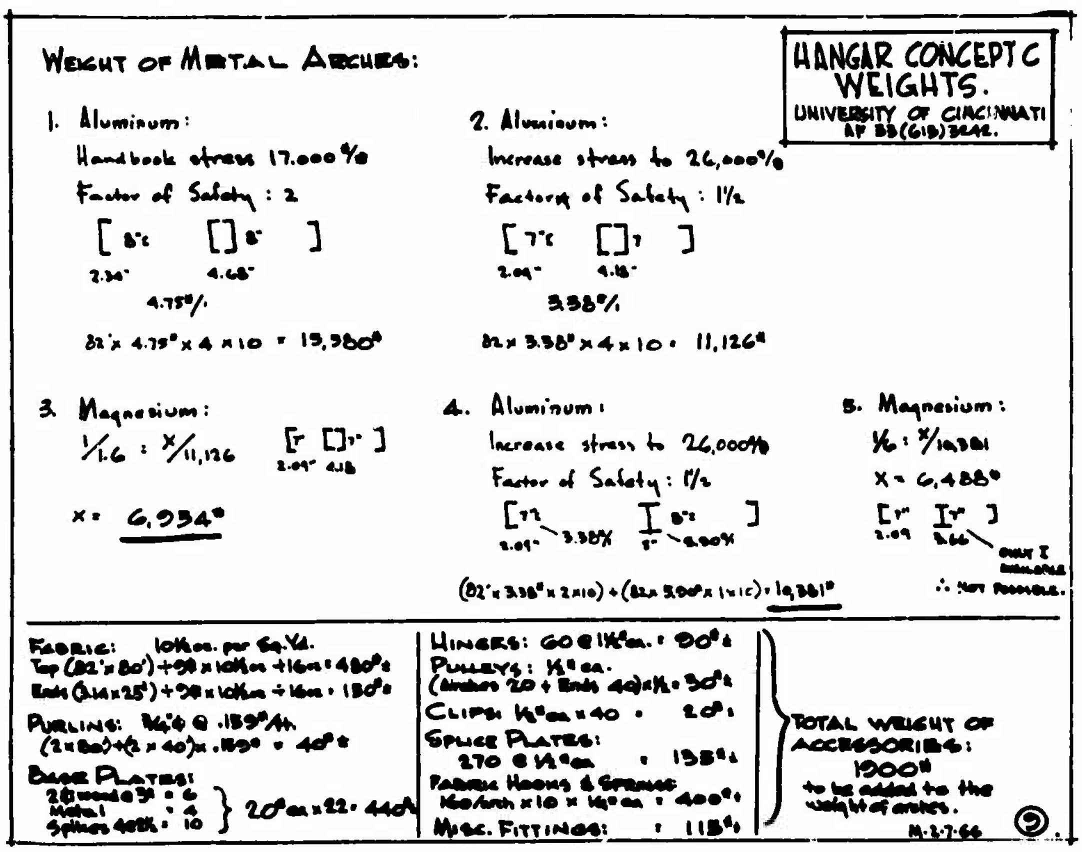


Figure 23. Concept "C" Weights

b. Concept "D"

As was the case in Concept "C", overall appearance of a Concept "D" hangar remained similar to that shown in the earlier presentation. (See Figure 14). Figures 24 through 32 describe pertinent aspects of this concept and served as the basis for the visual presentation made at the February meetings. The following remarks supplement the illustrative plates presented.

Elevations and basic module (Figure 24) illustrate the basic double curvature module. Overall size is 6'-8" wide by 8'-2 1/16" long and, as such, is compatible with the 463L pallet system. Side and end elevation views show the staggered horizontal joint method of assembly to impart structural rigidity to the assembled structure.

Module Detail (Figure 25). In section and exploded perspective views, the sandwich composition and suggested horizontal and vertical treatments are presented. Suggested faces of the composite sandwich are .025" fiberglass reinforced plastic, and a 2" thick paper honeycomb is shown as the core material. Experimentation with expanded honeycomb revealed that the material naturally assumed a double curvature saddle-like configuration when warped along one axis. A tongue and grooved horizontal joint (secured and strengthened by periodic luggage type fasteners) is shown. The vertical joint between arches is secured by a heavy fiberglass flashing tab adhered permanently to the modules of one arch and lapping over the modules of the adjacent arch.

Flashing Details (Figure 26). Modifications of the horizontal and vertical flashing tabs to provide sealing at module intersections are shown here.

Module Types (Figure 27). The 114 full modules and 12 half modules required to construct a 50' x 80' hangar are broken down into five types of full modules and two types of half modules, and required quantities of each are spelled out. The variations are due principally to orientation of male and female components of the tongue and grooved horizontal joints for weathering purposes.

Erection Procedure (Figures 28 and 29). Site preparation involves laying out two parallel rows (52' apart) of base pads. Within each row, base pads are anchored and leveled 6'-8" center to center. Modules are assembled into an arch on the ground and, in the case of the end arch, the fabric end curtain is attached. Figure 29 illustrates the five step procedure for raising a typical arch into a vertical position and securing it to the appropriate base pads. The following three sketches illustrate the erecting of a second arch and the lapping of its vertical flashing tabs over the previously erected arch.

Securing Hardware (Figure 30). Jacks, base pads, and arch clamps utilized in the erection procedure are illustrated in this plate.

Packaging (Figure 31). Palletizing of hangar components is illustrated and shows need for three leaded pallets plus one box for assorted hardware items.

Weights and Cubage (Figure 32). Total packaged weight of a Concept "D" hangar is estimated at 6000 pounds and total cubage at 1500 cubic feet. Figures do not include weight and cubage of the pallets utilized.

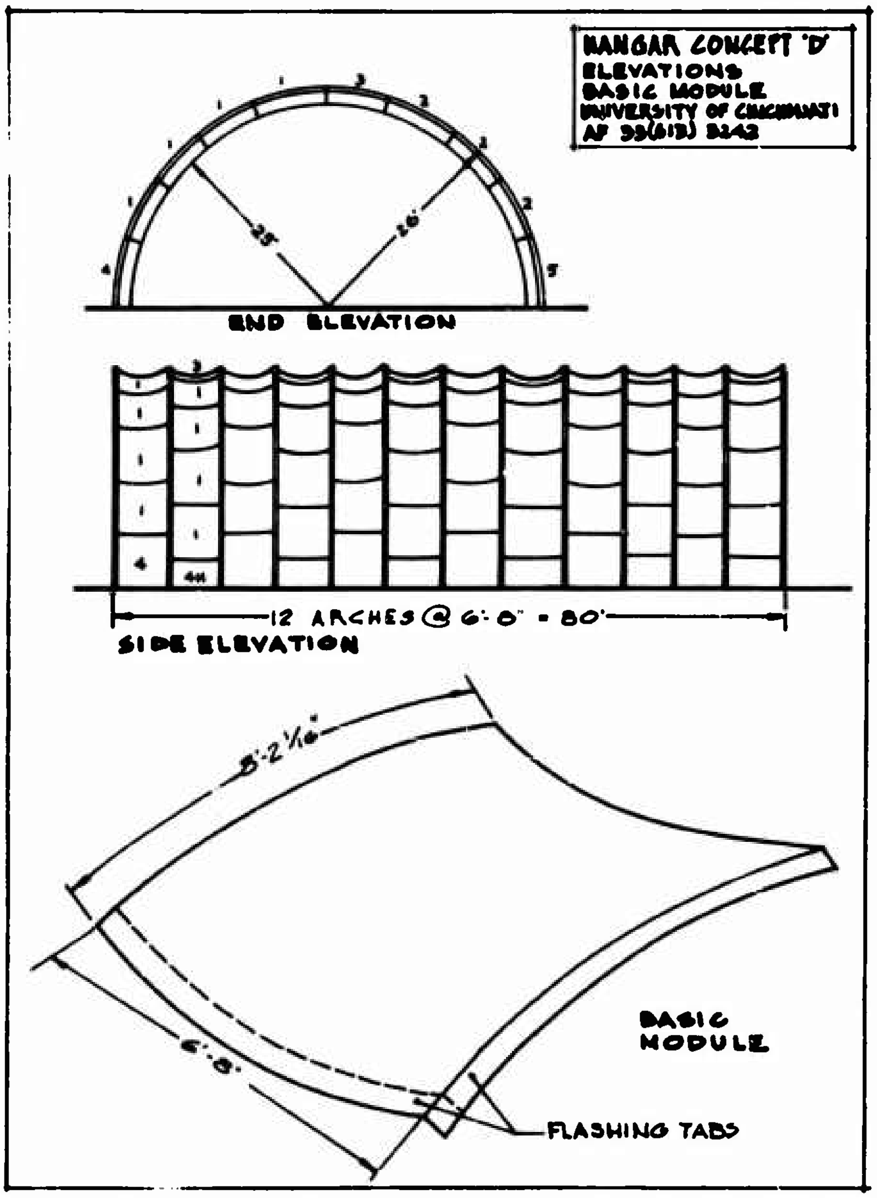


Figure 24. Concept "D" Elevations and Basic Module

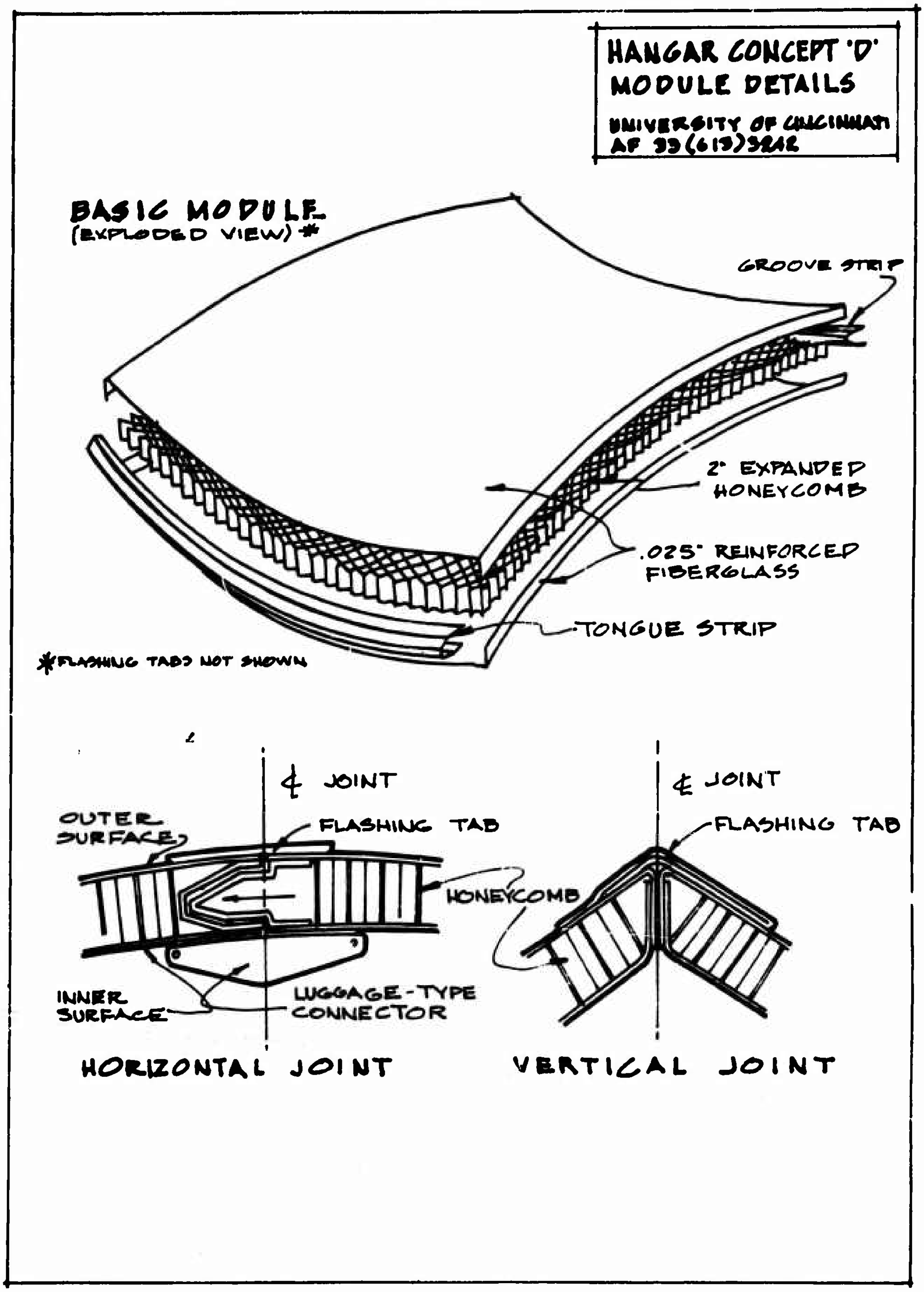


Figure 25. Concept "D" Module Details

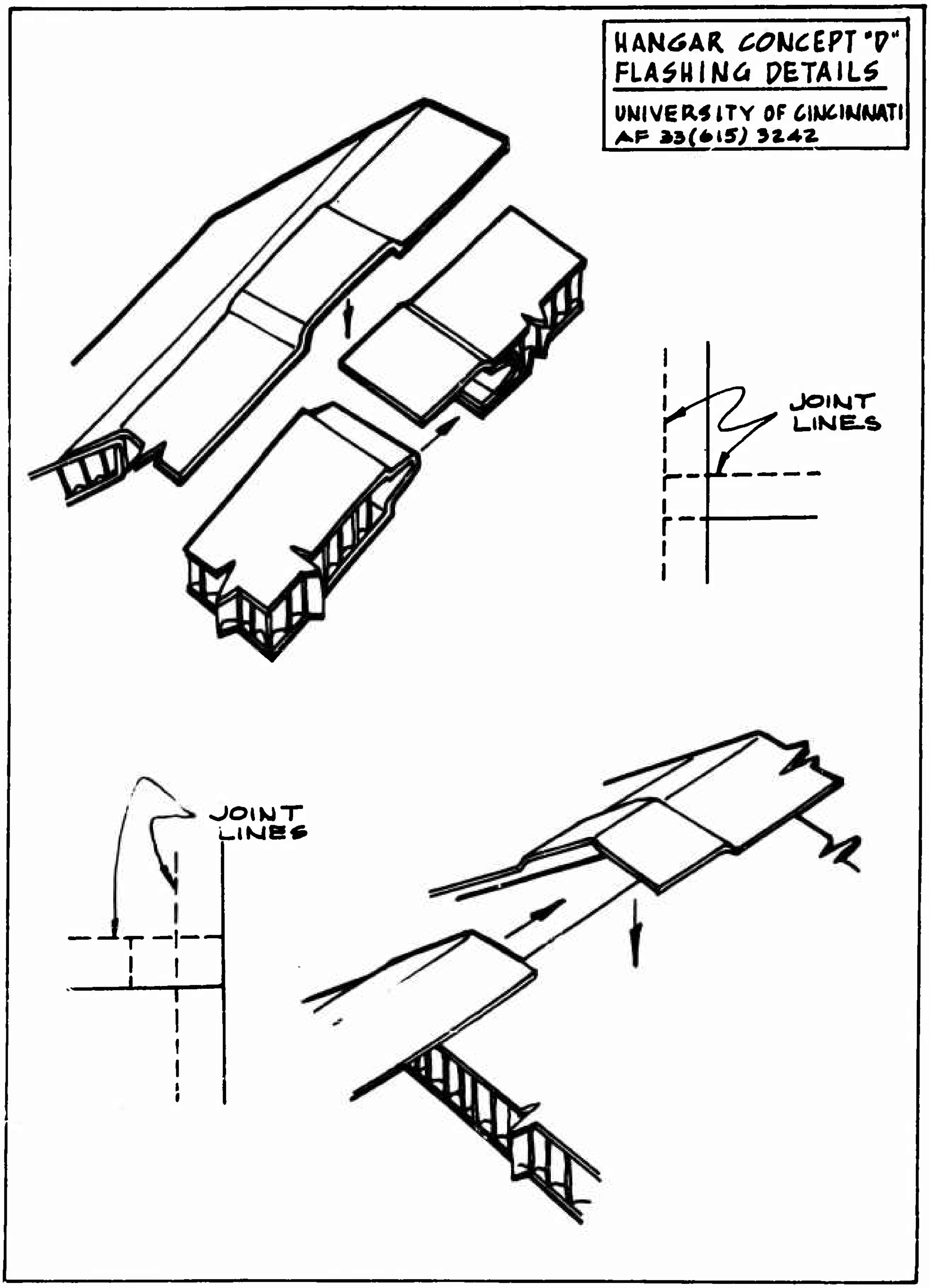


Figure 26. Concept "D" Flashing Details

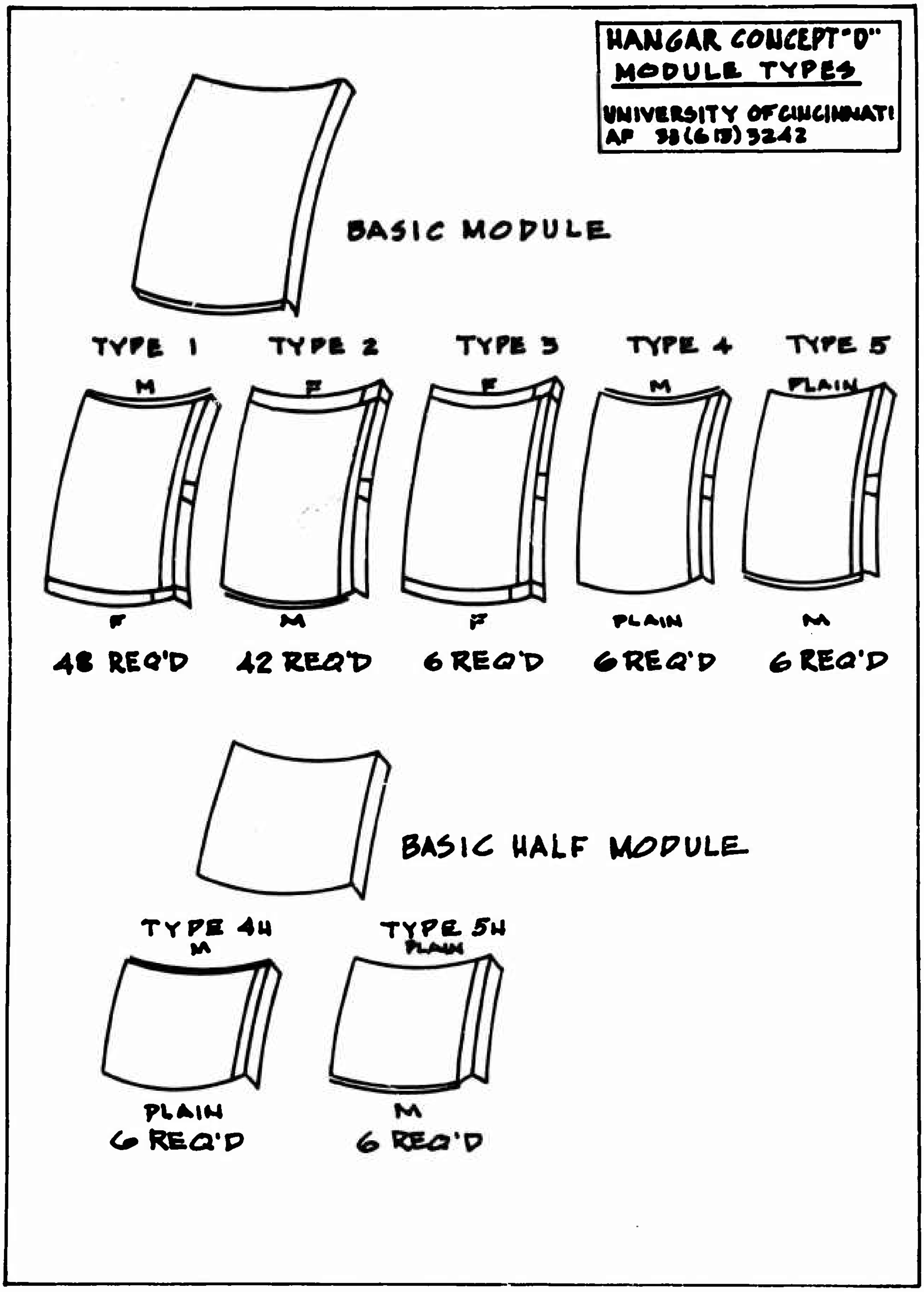


Figure 27. Concept "D" Module Types

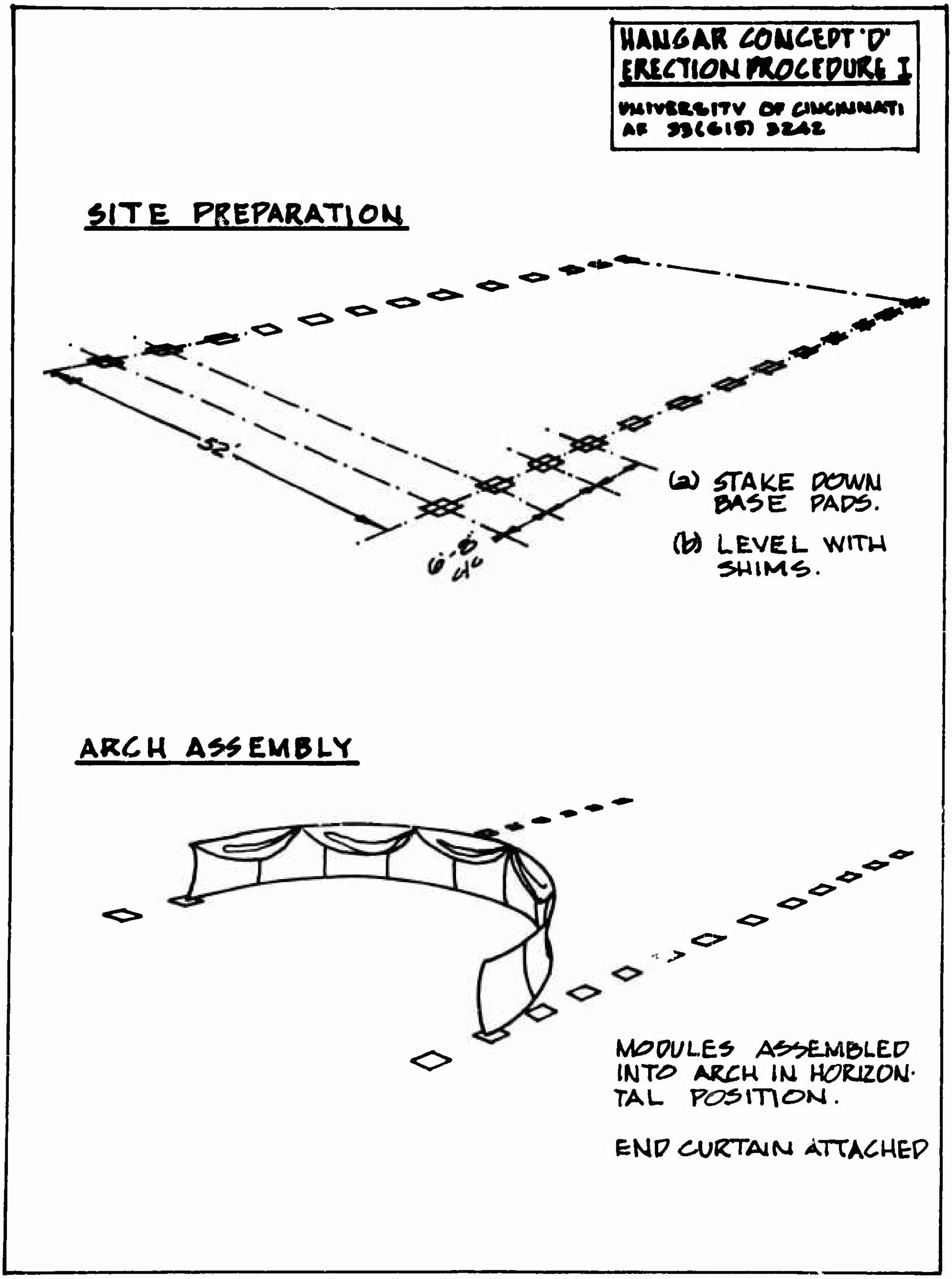


Figure 28. Concept "D" Erection Procedure I

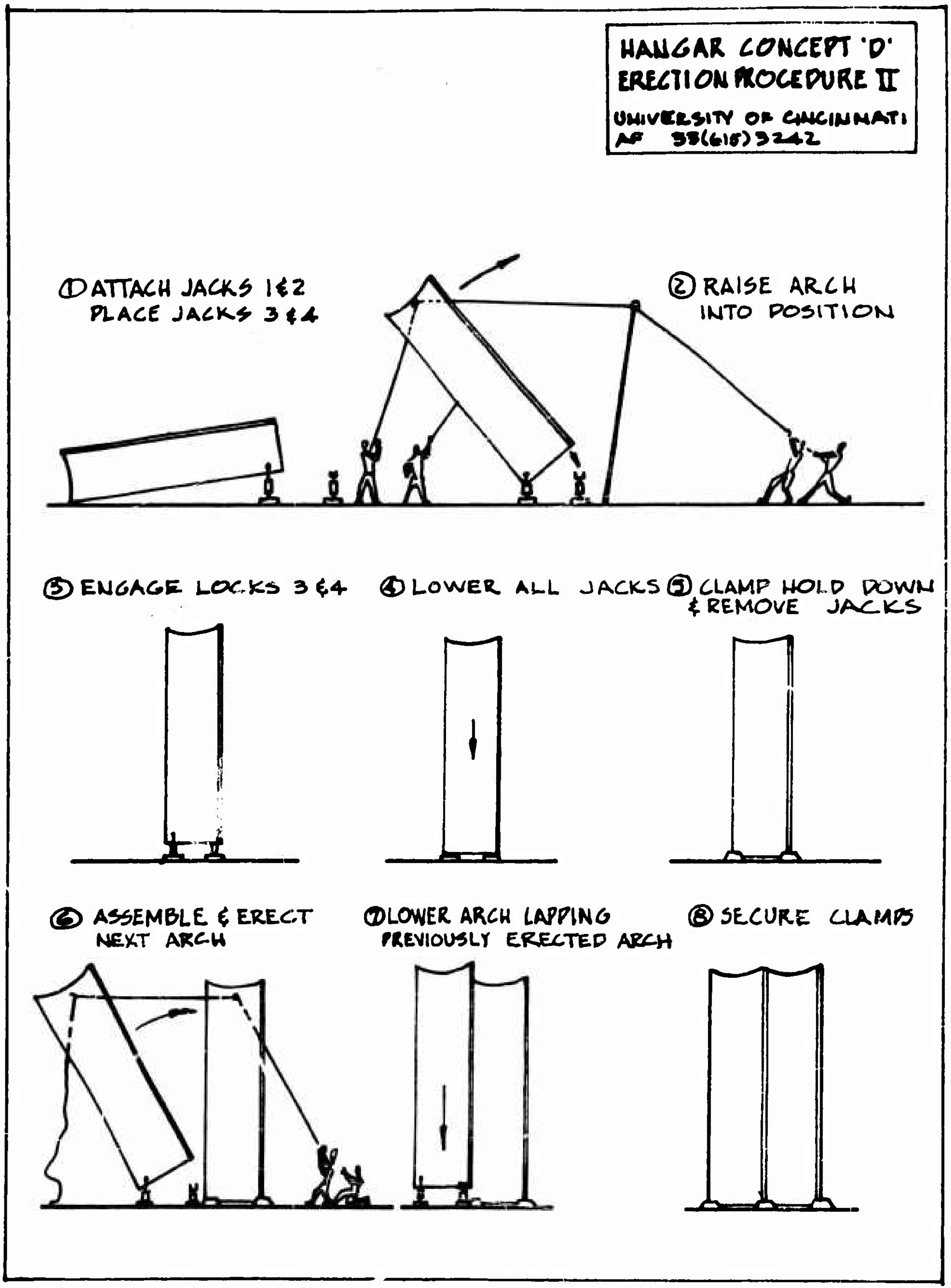


Figure 29. Concept "D" Erection Procedure II

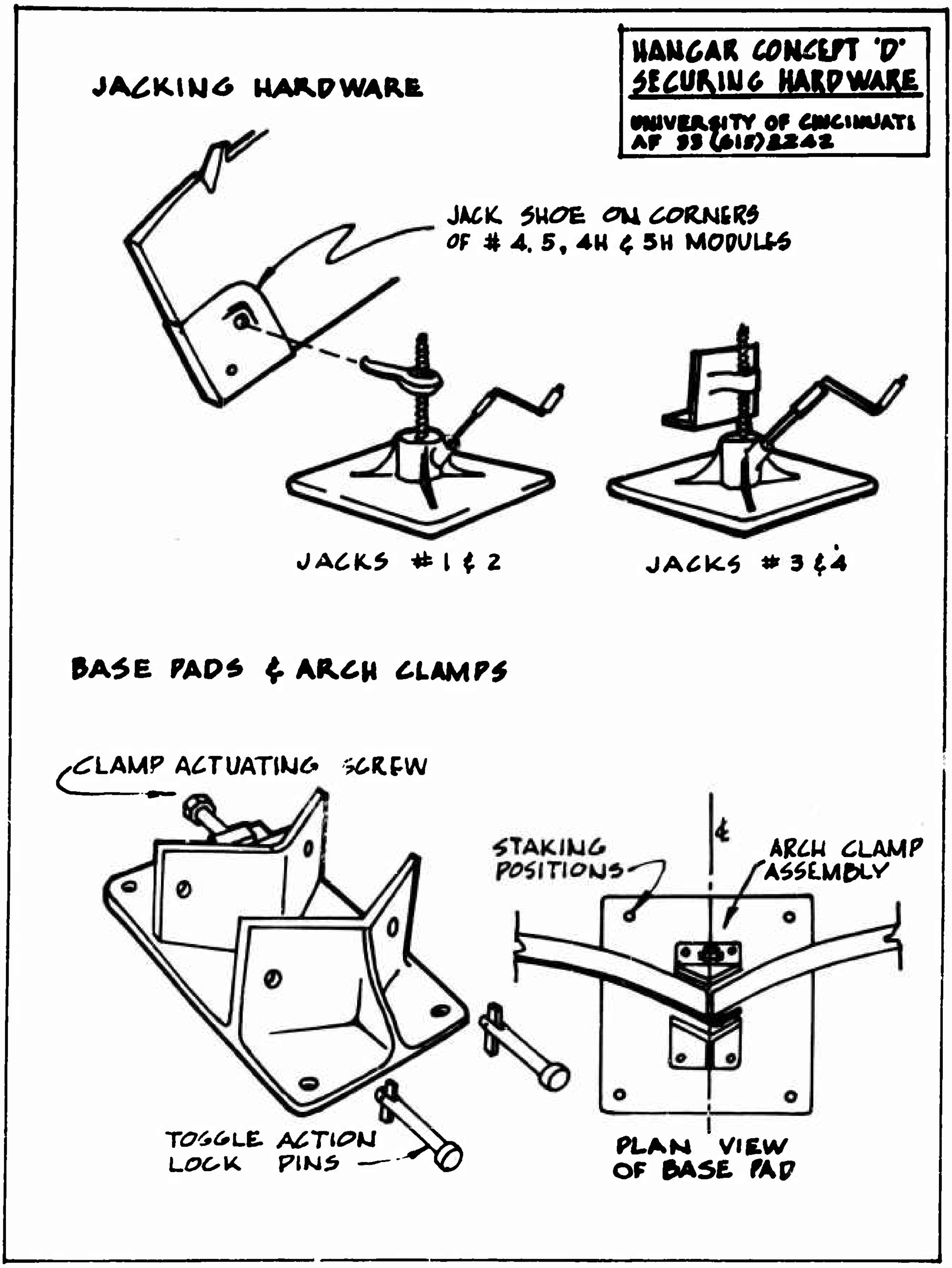


Figure 30. Concept "D" Securing Hardware

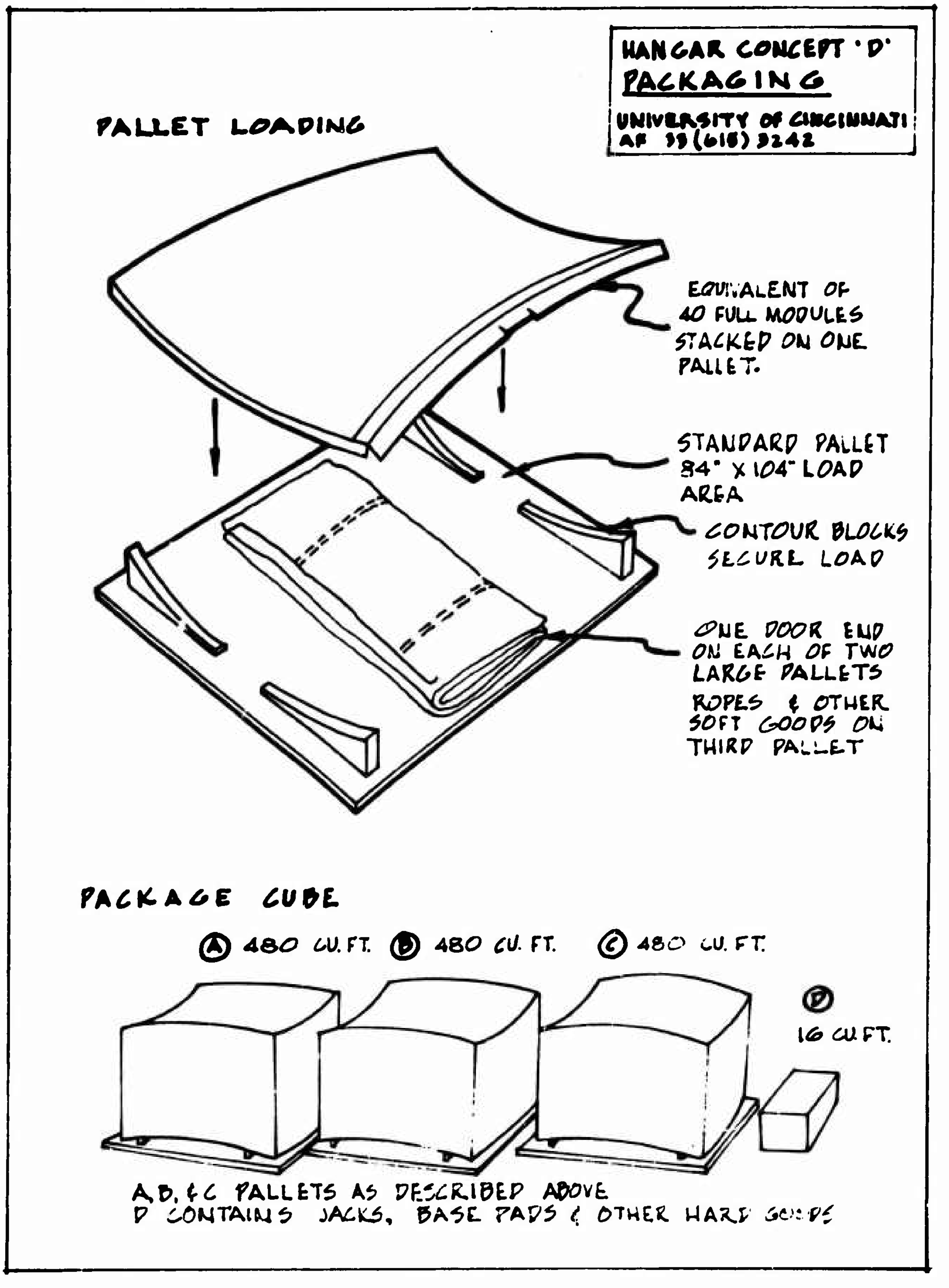


Figure 31. Concept "D" Packaging

HANGAR CONCEPT 'D'
WEIGHTS & CUBAGE

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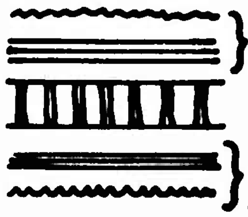
WEIGHT



3.88 OZ./FT.^{2}

3.37 OZ./FT.^{2}

3.88 OZ./FT.^{2}

11.13 OZ./FT.^{2}

PANEL AREA 6,561 FT.^{2} x 11.13 OZ. =	4508 LB.
FLASHING	310 LB.
TONGUE & GROOVE INSERTS	360 LB.
CLAMPS	112 LB.
BASE PADS	260 LB.
ERECTION HARDWARE	200 LB.
FABRIC ENDS (2)	250 LB.
TOTAL WGT. PER HANGAR	6000 LB.*

CUBAGE

PANELS & SOFT GOODS (3 PALLETS @ 480 FT.^{3} EA.)	1440 CU. FT.
HARDWARE (1 PALLET @ 60 FT.^{3})	60 CU. FT.
TOTAL CUBAGE PER HANGAR	1500 CU. FT.*

* DOES NOT INCLUDE PALLET

Figure 32. Concept "D" Weights and Cubage

c. Concept "D-1"

A variation of Concept "D" had evolved earlier and is shown in Figure 33 as Concept "D-1". It suggested use of a single curvature module with a V-shaped cross section in lieu of the double curvature one utilized in Concept "D". It was viewed as a fall back concept if, for some unanticipated reason, material or cost factors made the double curvature configuration unusable. The previously cited natural tendency of the expanded honeycomb to assume a saddle configuration reinforced the conviction that the double curvature module was attainable and structurally more logical.

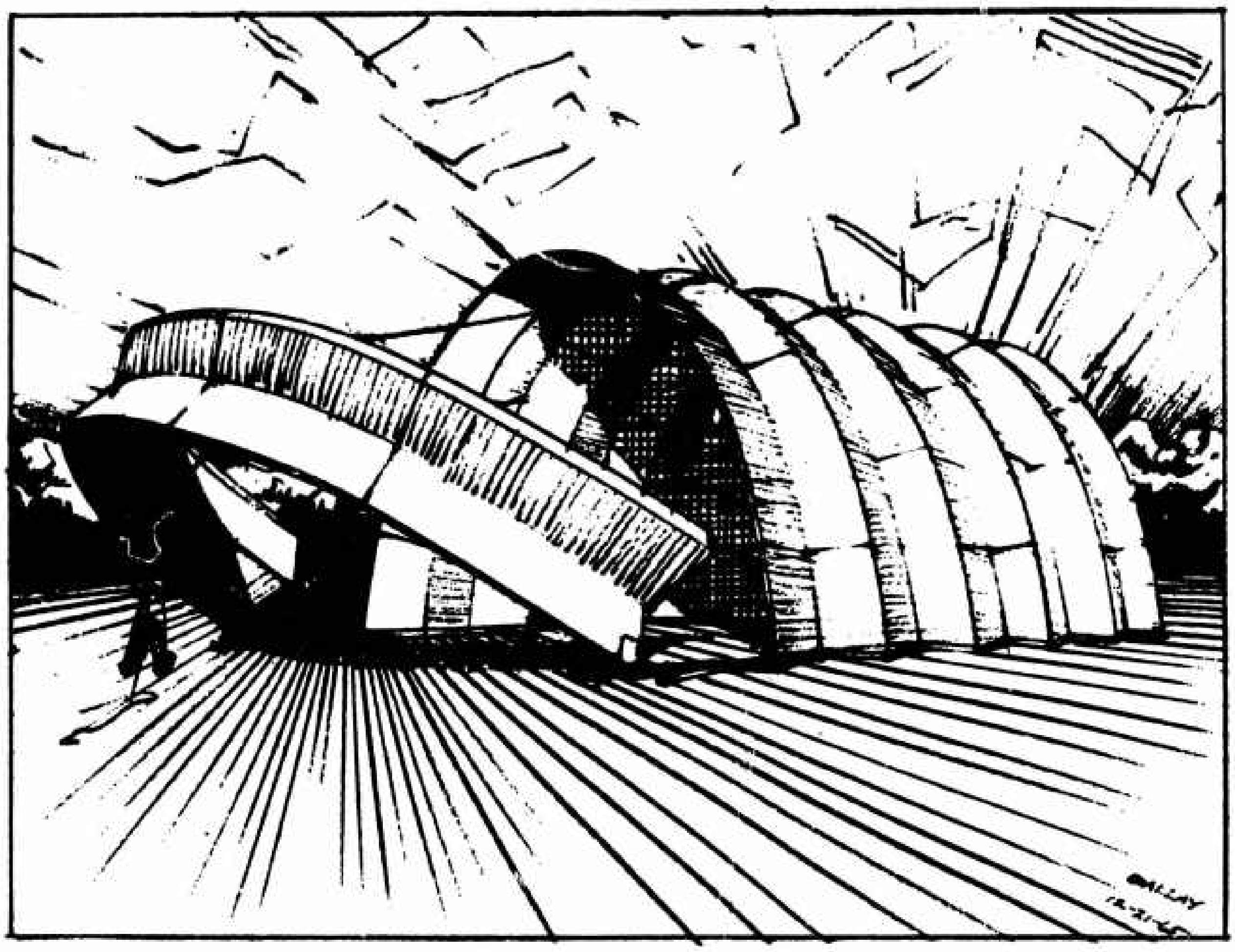


Figure 33. Concept "D-1" V-Section Module

C. EVALUATION OF CONCEPTS

The result of the deliberations at the 9 February 1966 meeting was the selection of Concept "D" (double curvature module) as the concept to pursue further and eventually produce in full size prototype form.

As well as Concepts "C" and "D" previously submitted, Concepts "A" and "B" had been briefly reviewed at this meeting. It was the general feeling that Concept "A" (Three-Hinged Arch) was, as noted in the December critique, "the most conventional" one presented and similar to other existing structures. Concept "B" (Space Frame and Composite Plate and Linear Elements) was too complicated and might well require specially trained personnel for erection. The Air Force was rèluctant at this time to pursue further an essentially fabric structure, so Concept "C" was eliminated from further consideration.

It was felt that Concept "D" combined a uniqueness and simplicity with an apparent appropriate advance in the state of art. Basic feasibility of the construction techniques of the double curvature module was demonstrated with several one-third scale fiberglass faced paper honeycomb cored panels that were fabricated by hand lay-up process prior to the meeting.

Areas of concern that should be borne in mind in the further development were:

1. Cost
2. End wall operation and heat loss
3. Anchoring in poor soil
4. Possible leakage in panels and accumulation of moisture in honeycomb cells

Further specifications were laid down and included:

1. Full size hangar was to have one rigid and one insulated fabric end wall
2. Openable fabric end should have sill or tie down capable of being left in place so that planes could pass over it
3. Rigid end wall should have some translucent panels, ventilation provision, and access doors large enough for use by trucks
4. Black out capabilities should be provided
5. Leveling should be made as simple and non-critical as possible
6. There should be a mechanical lock from arch to arch
7. Tension ties should be provided across the base

of each arch to prevent spreading

8. A kit of lighting fixtures and plug-in receptacles should be provided

9. Color: olive drab or a lighter value green/brown color acceptable

10. Panel materials should be thoroughly evaluated in respect to possible warpage.

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III

DOUBLE CURVATURE CONCEPT DEVELOPMENT

The decision having been made to develop further the Double Curvature Concept (previously designated "Concept D"), concurrent effort was directed for the next several months along the following three lines: model making and testing, further development of design details, and searching out sub-contractors and negotiating a subcontract.

A. MODEL MAKING AND TESTING

Models made for testing and demonstrating were undertaken in two scales: 1/3 full size and 5/8" = 1'-0".

1. One Third Full Size Models

An improved wood mold was fabricated for the one third scale bidirectionally curved modules, and ten modules were produced. 3/4" cell paper honeycomb was used as the core and hand laid-up fiberglass reinforced polyester was used as skins.

The purpose of this exercise was more to experiment with joining and erection techniques and to get the feel of the elements at a reasonable scale than to use the modules for highly sophisticated structural analysis.

On these ten additional modules tongue and grooved horizontal joints were laid up along the appropriate edges of the panels. They were fabricated of tempered fiberboard. Luggage type connectors were attached near the outboard edges of the horizontal joint lines on the interior faces of the modules.

On 18 April 1966 a full arch was assembled and erected outdoors on the University campus (Figure 34). Assembly and erection was accomplished by three men in about three minutes time (the arch was 16'-8" across the base and 8'-4" high). As reported at the time, "No anchorage was provided, and the arch was set up on a slightly irregular grass turf. A gusty breeze developed and the arch would deflect into a slightly elliptical shape and then return to its circular shape. These alternating deflections continued for a short time, then abruptly the arch fell when the center joint at the ridge seemed to break outward."

Investigation after the failure showed that the fiberboard tongue and grooved joint had broken and that the fiberboard had failed in cohesion. An additional luggage-type latch at the center point may well have resisted the tendency of the joint to open.

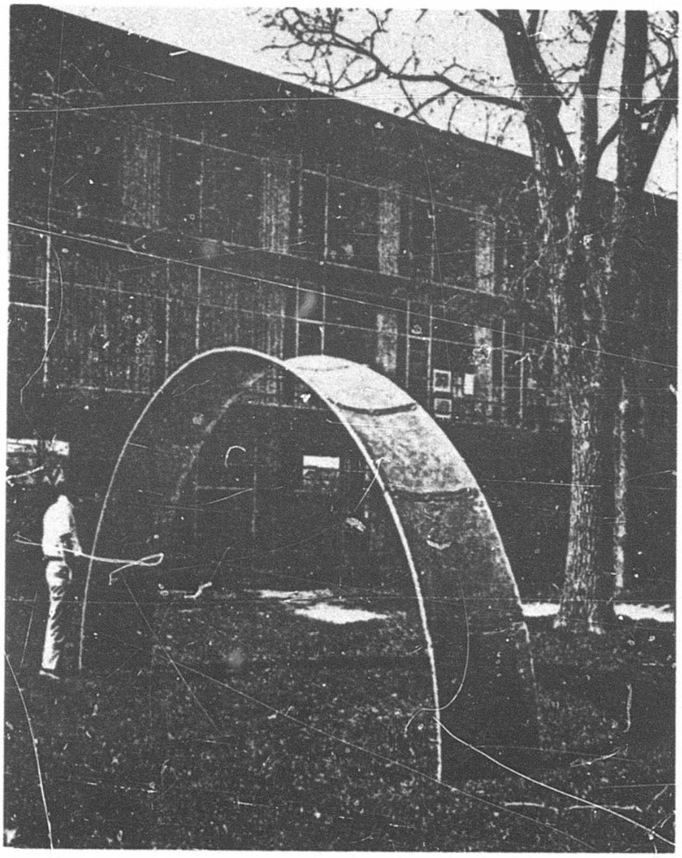


Figure 34. Concept "D" 1/3 Scale Test Arch

2. <u>5/8" = 1'-0" Scale Model</u>

Some 132 small vacuum-formed plastic modules and half modules were made and utilized to form a 5/8" = 1'-0" scale model of the double curvature concept hangar. As illustrated in the referenced sequences of photographs, the model was a useful tool in exploring:

a. Erection of arches by the tip-up method (Figure 35)

b. Erection of arches by use of a gantry crane (Figure 36)

c. Variations of flexible end walls (Figure 37)

d. Erection of rigid end wall (Figure 38)

The tip-up technique of erecting arches remained the favored approach. It was realized any final decision would depend on such details as arch to arch connections and jack details. A decision on the type flexible openable end wall would depend on, among other things, calculation of wind loads on the end wall and the means of withstanding these loads.

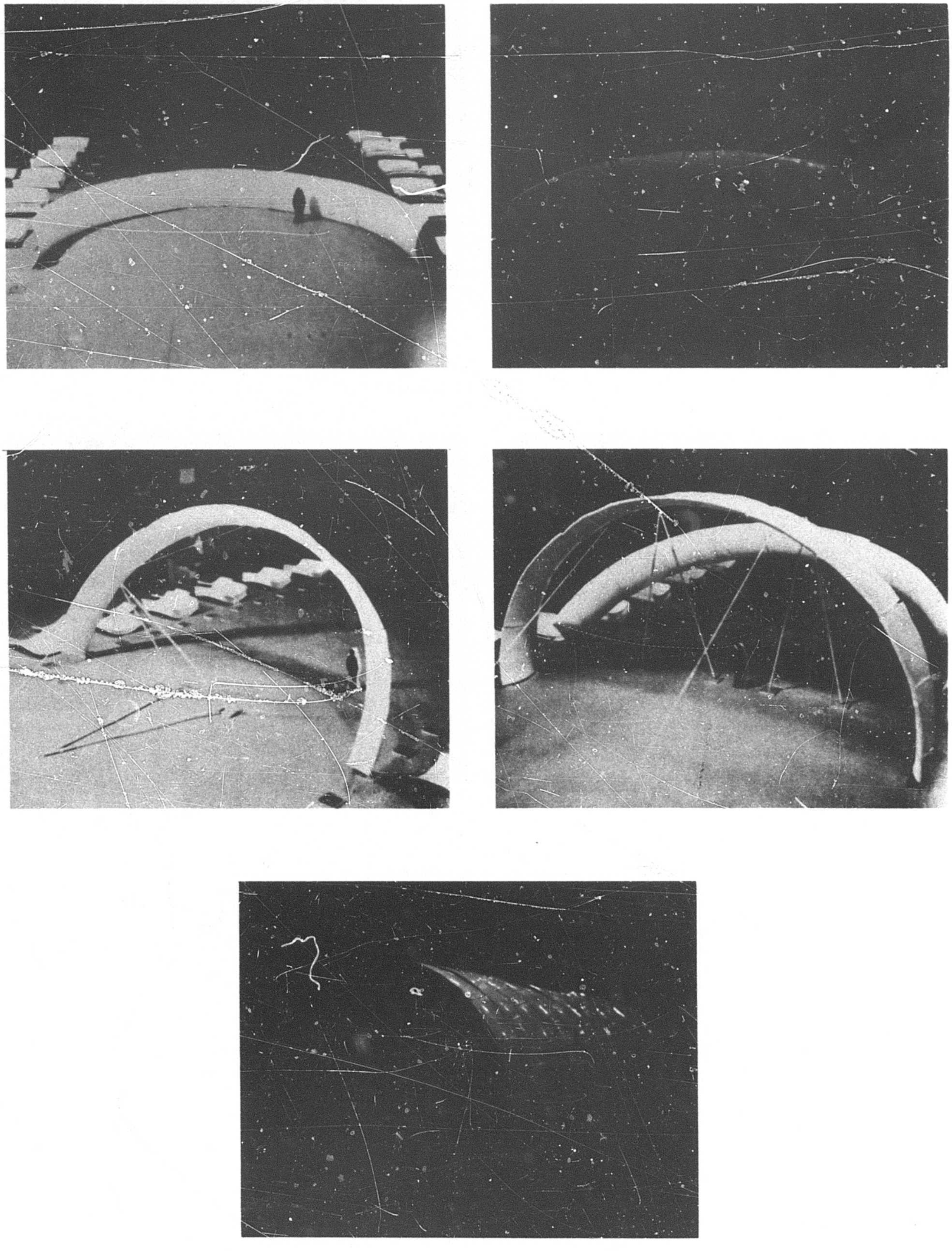


Figure 35. Erection of Double-Curvature Arches by Tip-Up Method

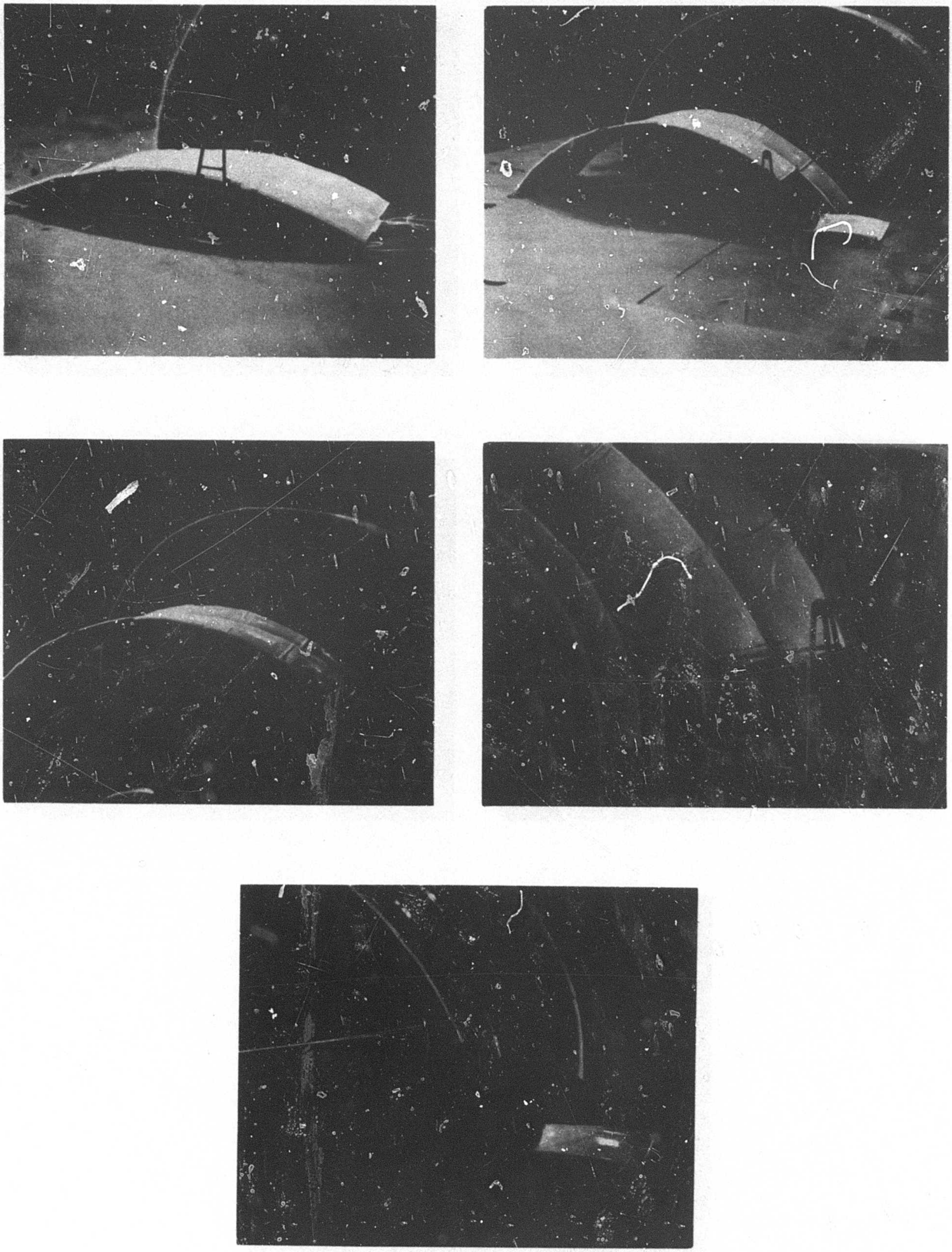


Figure 36. Erection of Double-Curvature Arches

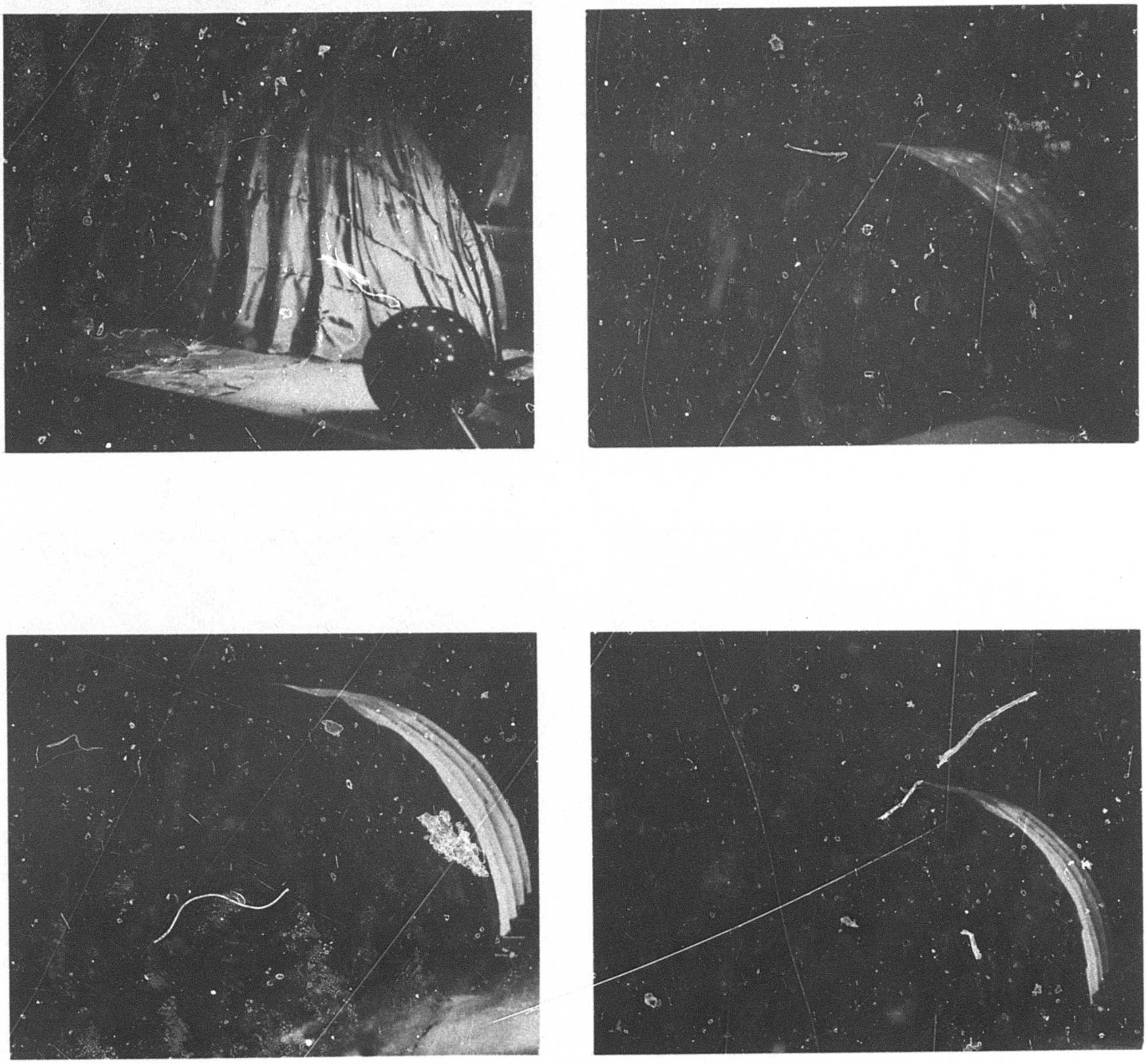


Figure 37. Flexible End Wall Studies

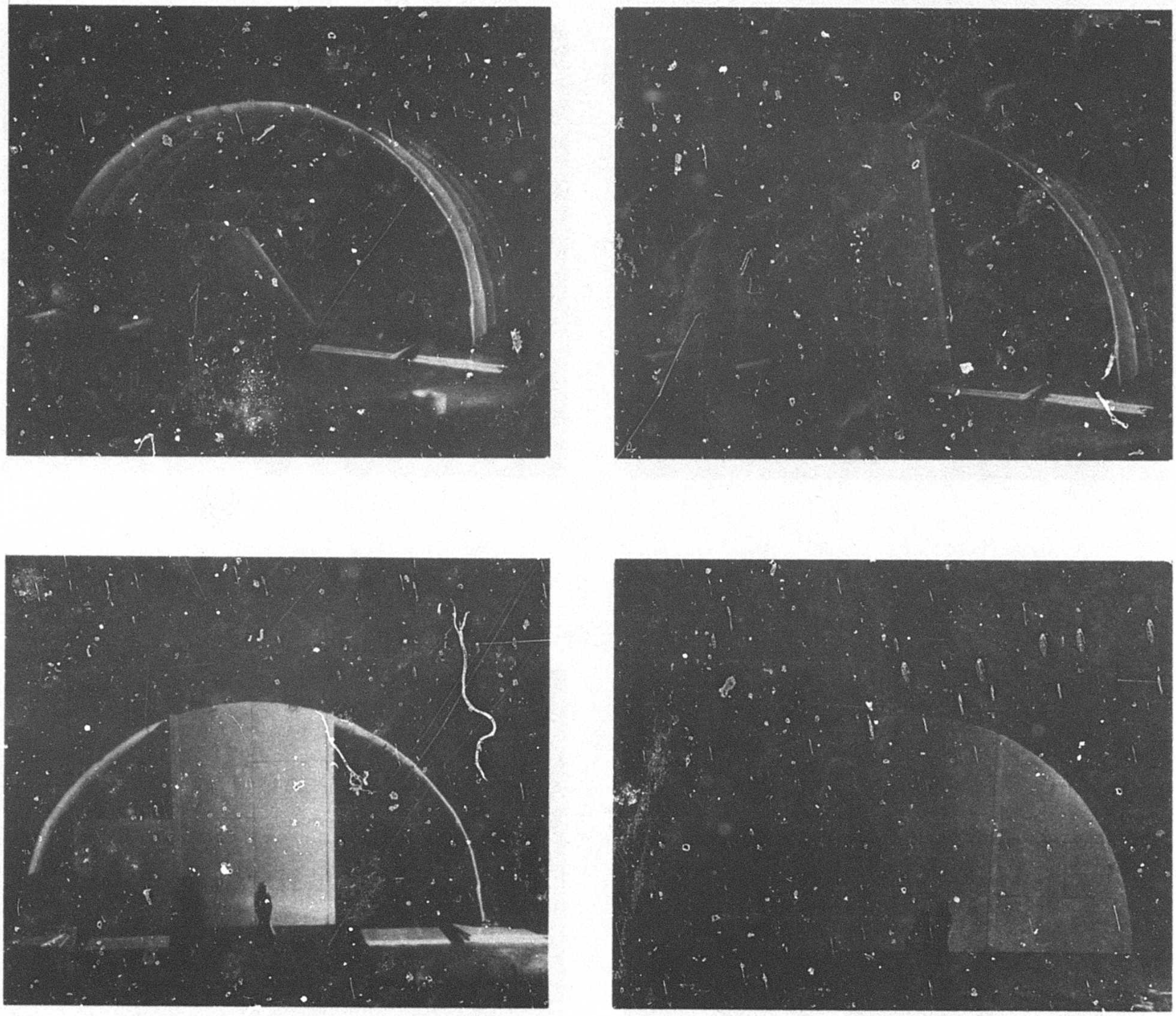


Figure 38. Fixed End Wall Erection

B. FURTHER DEVELOPMENT OF DESIGN DETAILS

While a broad search for a suitable subcontractor for detailed engineering was being conducted, further design studies were made on several aspects of the concept. These areas included:

1. Flashing of Vertical Arch to Arch Joints

Alternates to the fixed fiberglass tab (Figure 25) were studied; prominent was one that involved drawing (or rolling) a fabric flashing over each joint and securing by drawing taut and anchoring tension lines sewed into hems of the fabric strip.

2. Horizontal Joint Connectors

Cam-locks anchored securely within the sandwich construction were considered as alternates to the luggage type latches installed on the 1/3 scale model.

3. Vertical Joint Connectors

A "zipper" concept of combination flashing and connector was considered (Figure 39). This concept also involved an inflatable tube keyed into the edge of one arch with inflation occurring after installation of the "zipper". It was feared that accumulative friction of the "zipper" plates being dragged over the arch would be considerable.

Following the directive to provide fixed mechanical connections between arches, several approaches were explored. These included 4" wide "F"-shaped extrusions that would be bolted to the edges of panels and then bolted together through the stems of the "F"s, lacing together through removable hooks on the underside of the arches, and two schemes for utilizing straps, recessed locking cams, and/or metal rings and Velcro.

Trade offs were made indicating the amount of auxiliary erection equipment that several methods would require. They ranged from none at all to scaffolding the height of the full arch. It was recognized that detailed engineering calculations would have to be made before this matter could be resolved.

4. Openable Fabric End Walls

A theater-like curtain, dropped via parallel lines or pulleys to the ground, disconnected and carried to each side of the opening was proposed. Aerodynamic sloped configurations were also investigated as was a 2-part curtain that was pulled to the respective sides of the arch with cables and pulleys.

5. Fixed Fabric End Wall

Variations for vertical plane and sloped configuration end walls with roll up truck access flaps were studied.

6. Arch Erection Methods

A method utilizing a single double-A frame (Figure 35) was studied as was one using two such frames. Alternate methods employed a scissors type dolly or a gantry crane (Figure 36) to erect arches singly or in attached pairs.

C. SUBCONTRACTING EFFORT

It was recognized that competent subcontracted assistance would be required in detailed structural analysis, engineering design and sandwich panel construction and testing.

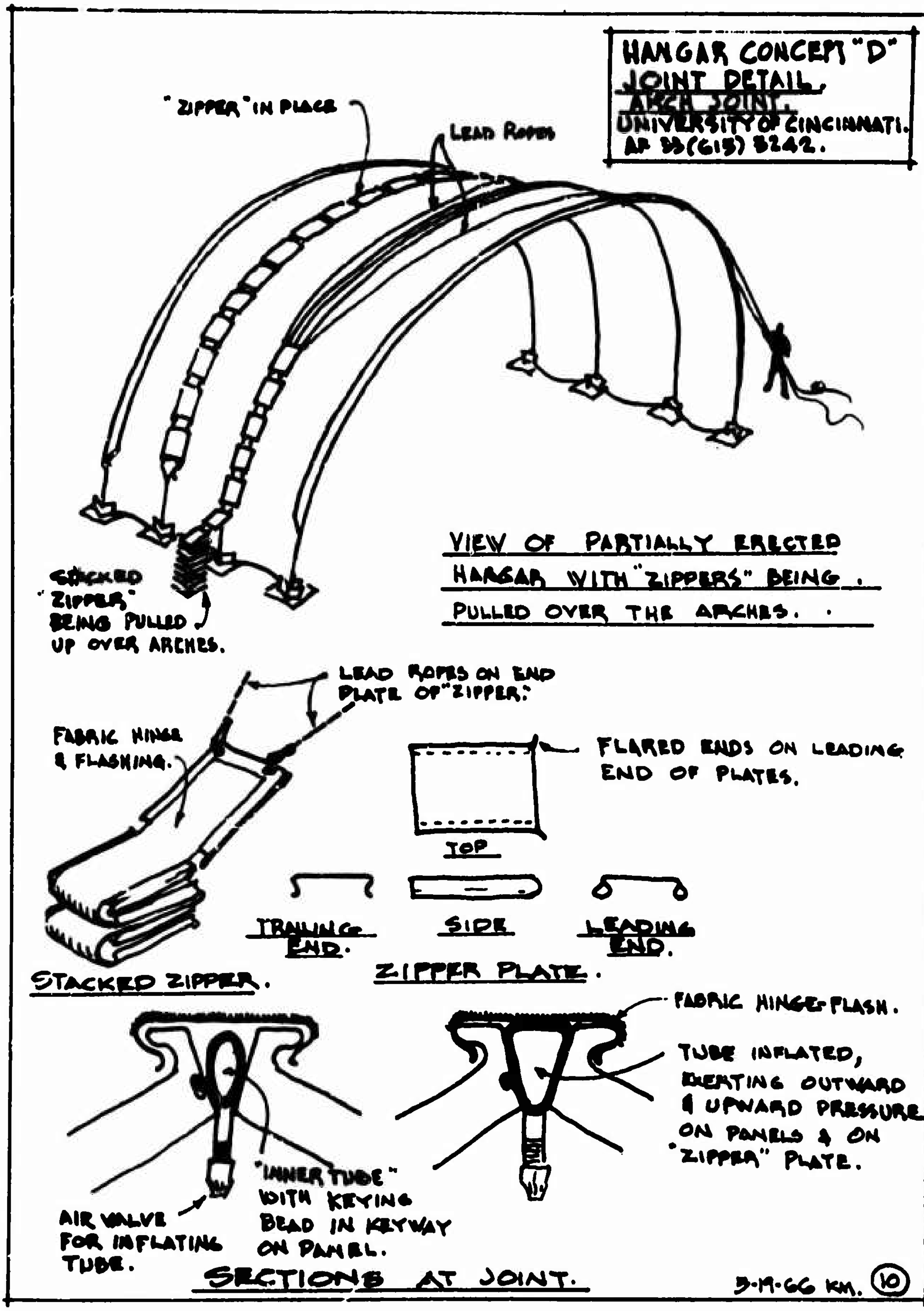


Figure 39. Vertical Joint Detail "Zipper" Concept

A broad search was initiated for the best subcontractor. Especially important was the experience of such a firm in the area of plastic-faced honeycomb-cored panel technology.

Among the firms contacted and/or visited were: Brunswick Corporation, Dentin Manufacturing Company, Eldon Fiberglass Manufacturing Company, G. T. Schjeldahl Company, Goodyear Aerospace Corporation, Hitco, Reichold Chemicals, Inc., Smith Fiber Glass Products, Inc., and Whittaker Corporation.

The following firms were visited to discuss materials and plastic technology: Cincinnati Milling Machine Company, Dow Chemical Company, Fibre Glass Evercoat Company, Hexcel Products, Inc., Monsanto Chemical Company, and Shenandoah-Pacific, Inc.

On the basis of demonstrated capacity, intent, preliminary recommendations and cost, the Whittaker Corporation was recommended to be the subcontractor. Air Force approval was obtained, and a subcontract was signed (effective date 1 July 1966) based on a one man-year effort divided among the categories of engineering, design, stress analysis, and process engineering.

D. COLLABORATIVE DEVELOPMENT WITH THE WHITTAKER CORPORATION

During the period between July 1966 and January 1967 intensive work toward finalizing details and materials was performed by the contractor and the subcontractor, the Advanced Structures Division of the Whittaker Corporation in La Mesa, California.

The subcontractor's extensive experience in composite sandwich construction and adhesives proved of great value during this work. Though distance sometimes proved an inhibiting factor to even closer cooperation, good liaison was established, and several lengthy conferences at La Mesa, Cincinnati, and Wright-Patterson Air Force Base provided personal interchange of ideas.

The subcontractor's first progress report recommended retaining the basic double curvature 6'-8" x 8'-2" size module but suggested possible reduction of the core thickness and increase of skin thickness. Reversing an earlier feeling that each arch could be structurally self sustaining, the subcontractor now indicated that a positive vertical joint connection between arches was necessary. A different approach to weather sealing between arches (utilizing neoprene or bulb gasketing) was proposed. It was hoped to simplify erection procedure by eliminating the jacking and lowering into position the overlapping flashing tab approach would have required.

The precision of alignment required by the horizontal joint connectors proposed by Whittaker was a cause for concern and follow-on study.

1. <u>Conferences at La Mesa - August 31 - September 2, 1966</u>

A thorough review was held by key contractor and subcontractor personnel and the following decisions, among others, were made:

a. The honeycomb panel should be encased in aluminum edge extrusion (an "H" section was tentatively agreed upon).

b. The critical element structurally is the horizontal joint.

c. At the vertical joint, the arches should be locked together (at least along the lower 12' of each side of the arch plus one connector at the top).

d. Pre-impregnated fiberglass was recommended because of lighter strength/weight ratio.

e. A metal sandwich (corrugated core with aluminum skins) was recommended for the rigid end walls. Stiffening columns were deemed necessary.

f. Any aerodynamic advantages from sloped end walls were deemed not worth the greater material complexity and cost such an approach would involve.

g. A continuous plywood strip along the base of the arches seemed preferable at the time to separate base pads.

h. Auxiliary tie downs were considered in high winds as a means of reducing the complexity of the horizontal joints.

. <u>Progress Reported November, 1966</u>

The following design studies and related efforts were reported:

a. A comparative study of module configurations of the same structural integrity were reported. Hangar weights utilizing the different types varied from 8,740 to 12,070 pounds.

b. The H-section edge extrusion on horizontal joints would be taken by pins. Quarter turn fasteners and a neoprene strip would complete this detail. No loose hardware would be employed.

c. A male and female bi-taper fitting was developed for the vertical joint. Four such connections would be used for each module (40 per arch).

d. A continuous combination flashing and neoprene bulb-weatherstrip arrangement had been selected.

e. An aluminum cast or welded base bracket contained a position for a pivot pin (for raising an assembled arch to its final position) and a guide slot (for directing the adjacent arch into a position approximately 1" from the erected arch).

f. A marine plywood (or in high quantity production, a honeycomb construction) continuous strip in 80" lengths would position base brackets and be reinforced and aligned with continuous aluminum edge channels.

g. Analysis proved that the structural contribution of guy wires did not warrant the additional expense and erection time.

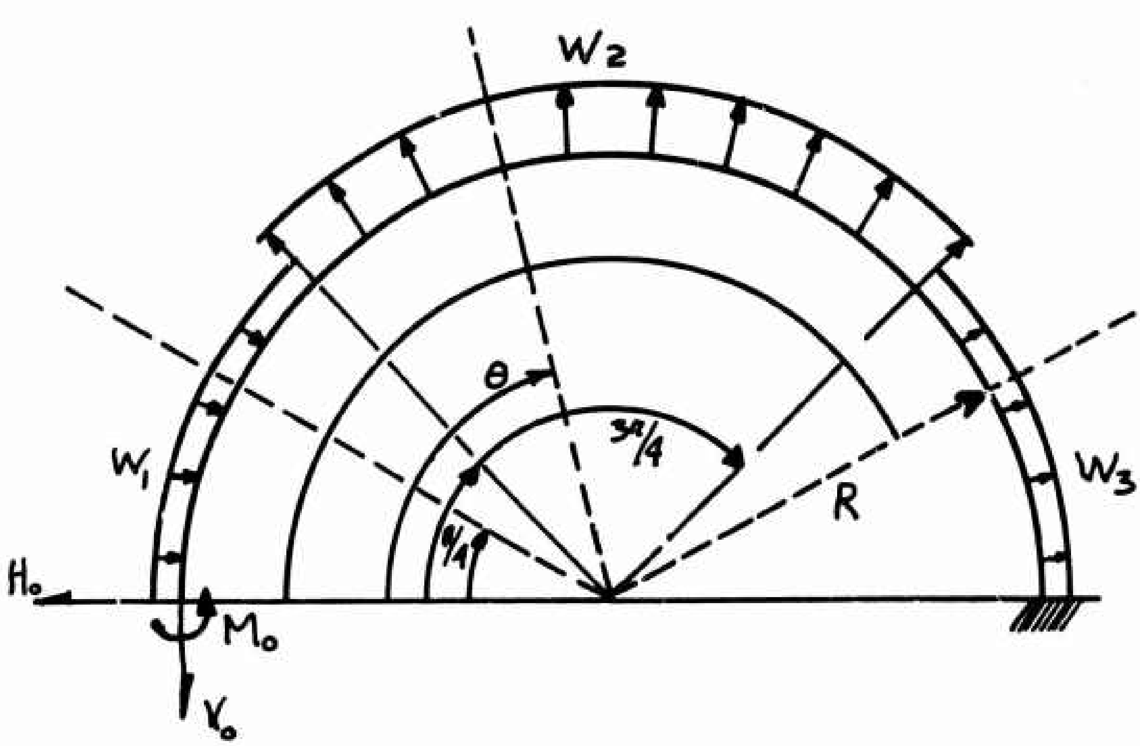
h. Four vertical beams proved necessary on both fixed and openable end walls. A neoprene-hypalon coated nylon fabric was recommended.

3. Proposals for Test Arches and Complete Hangars

At the direction of the Air Force, proposals were solicited for tooling up and fabricating two test arches, a full size hangar, and costing for a second hangar. Proposals were received from the Whittaker Corporation and a partial bid was received from the Goodyear Aerospace Corporation. These costs and final design details were prepared for an Air Force presentation scheduled for January, 1967 at Langley Air Force Base.

E. STRUCTURAL ANALYSIS, FINAL DESIGN

The Whittaker Corporation structural analysis for the 90 mph hangar employed a strain-energy technique, and the following equations were used:



$$w_1 = C_{d1}q \qquad q = 0.00256\ V^2$$

$$w_2 = C_{d2}q \qquad = 20.7 \text{ lbs ft}^2$$

$$w_3 = C_{d3}q$$

For zone: $0 \leq \theta \leq \frac{\pi}{4}$

$$M_\theta = -M_0 + H_0 R \operatorname{Sin}_\theta - V_0 R(1-\operatorname{Cos}\theta) - w_1 R^2 \theta \operatorname{Sin}\frac{\theta}{2} \qquad \text{-------1}$$

For zone : $\frac{\pi}{4} \leq \theta \leq \frac{3\pi}{4}$

$$M_\theta = -M_0 + H_0 R \operatorname{Sin}\theta - V_0 R(1 - \operatorname{Cos}\theta) - w_1 R^2 \frac{\pi}{4} \operatorname{Sin}(\theta - \frac{\pi}{8})$$

$$+ w_2 R^2 (\theta - \frac{\pi}{4}) \operatorname{Sin}\left[\frac{\theta - \frac{\pi}{4}}{2}\right] \qquad \text{--------2}$$

For zone $\frac{3\pi}{4} \leq \theta \leq \pi$

$$M_\theta = -M_0 + H_0 R \operatorname{Sin}\theta - V_0 R(1 - \operatorname{Cos}\theta) - w_1 R^2 \frac{\pi}{4} \operatorname{Sin}(\theta - \frac{\pi}{8})$$

$$+ w_2 R^2 (\frac{\pi}{2}) \operatorname{Sin}(\theta - \frac{\pi}{2})$$

$$+ w_3 R^2 (\theta - \frac{3\pi}{4}) \operatorname{Sin}\left[\frac{\theta - \frac{3\pi}{4}}{2}\right] \qquad \text{--------3}$$

Now, since the structure is "two-pin" type,

$$\frac{\partial U}{\partial M_0} = 0 \qquad \text{--------4}$$

$$\frac{\partial U}{\partial H_0} = 0 \qquad \text{-------5}$$

$$\frac{\partial U}{\partial V_0} = 0 \qquad \text{--------6}$$

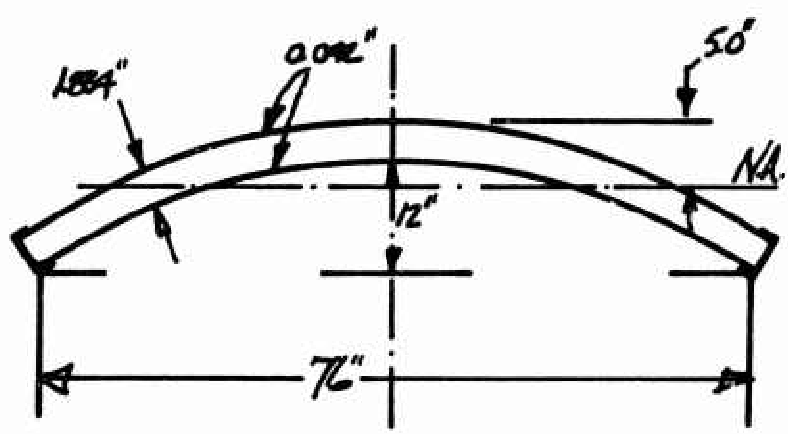
The mathematical solution of the above equations yielded the results for bending moment under 90 mph wind condition shown in Figure 40.

It should be noted that the results here are based on one arch of 6"-8" depth, 50' width of span by 25' height (h/ℓ ratio = 0.5). As far as load intensity and wind pressure are concerned, the results were compatible with any standard technical information available.[1]

F. STRUCTURAL DETAILS, FINAL DESIGN

1. Design of Composite Module

From the above loading requirements it was decided that a composite sandwich utilizing .042" fiberglass skins and 1.75" thick paper honeycomb core be used in the form shown.



Using the following relationship,

$$I_{n.a.} = TR^3 \left[\frac{\theta_2 - \theta_1 + \sin 2\theta_1}{2} - \frac{2(1 + \cos 2\theta_1)}{\theta_2 - \theta_1} \right]^{(1)}$$

the moment of inertia of the segment $I_{n.a.}$ was found to be

$$I_{n.a.} = 95.55 \text{ in}^4$$

---

[1]Seely and Smith, "Advanced Strength of Materials," J. Wiley, p. 70.

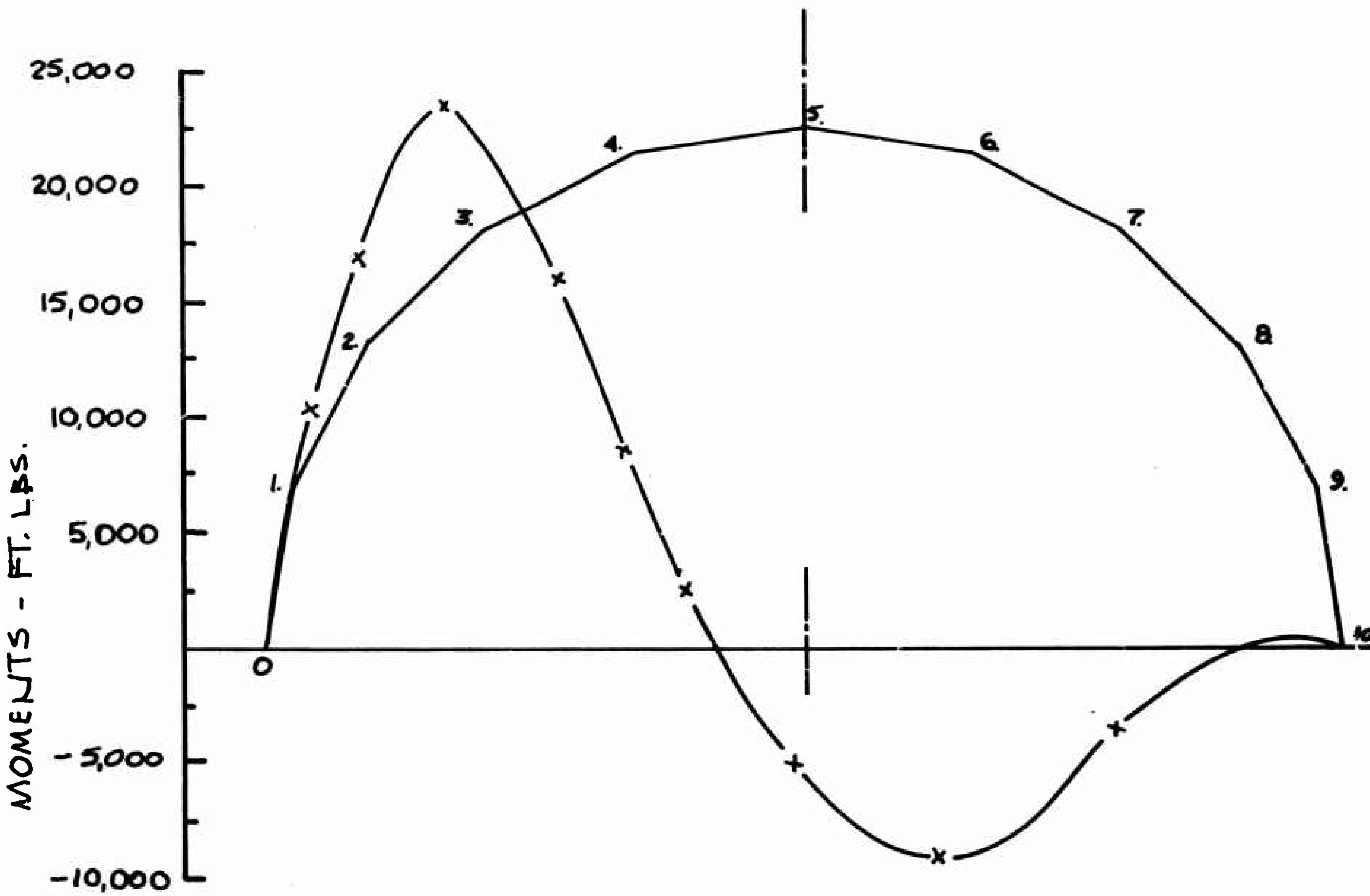


Figure 40. Bending Moment Across One Arch for 90 MPH Wind Load on Double Curvature Concept (Whittaker Corporation)

Therefore maximum bending stress induced into the structure due to wind loading alone would have been

$$\sigma_b = \frac{M}{I} c = \frac{248000}{95.55} \times 8.834$$

$$= 22900 \text{ psi} < 24000 \text{ psi yield.}$$

In selecting the type of core, the skin was checked against local buckling for different cell-size paper honeycomb. Hexcel KP-1/2-80-(18)EDF was found to be satisfactory since critical buckling stress in skin for this size paper honeycomb was:

$$F_{cr} = \frac{E_f}{3} \left[\frac{t_f}{R}\right]^{\frac{3}{2}}$$

where E_f = Modulus of Elasticity of fiberglass, t_f = Thickness of fiberglass skin, and R = Radius of cell size.

Hence, $$F_{cr} = \frac{1.5 \times 10^6}{3} \left[\frac{0.042}{0.25}\right]^{\frac{3}{2}} = 34500 \text{ psi}$$

2. Joints

a. Horizontal

For maximum bending moment on the arch, loads across panel modules were worked out and consequently size and number of "transfer pins" indicated earlier (Figure 41) were selected. Edge extrusions on panels were checked against bearing due to pin loads, and pins and skin/extrusion shear stress were checked to be within acceptable limits, especially for horizontal joints.

b. Vertical

Vertical joints (Figure 42) were designed to handle load due to shear caused by wind of frontal direction and consequent racking between arches.

3. End Walls

a. Fabric

A fabric end wall was designed for this structure. A number of cables were selected to be tied to the fabric in vertical direction to take tensile forces created by sagging of fabric in catenary manner. The sag of 15" was assumed for such cables (sag ratio, $\theta = h/\ell = 5\%$). Since the composite

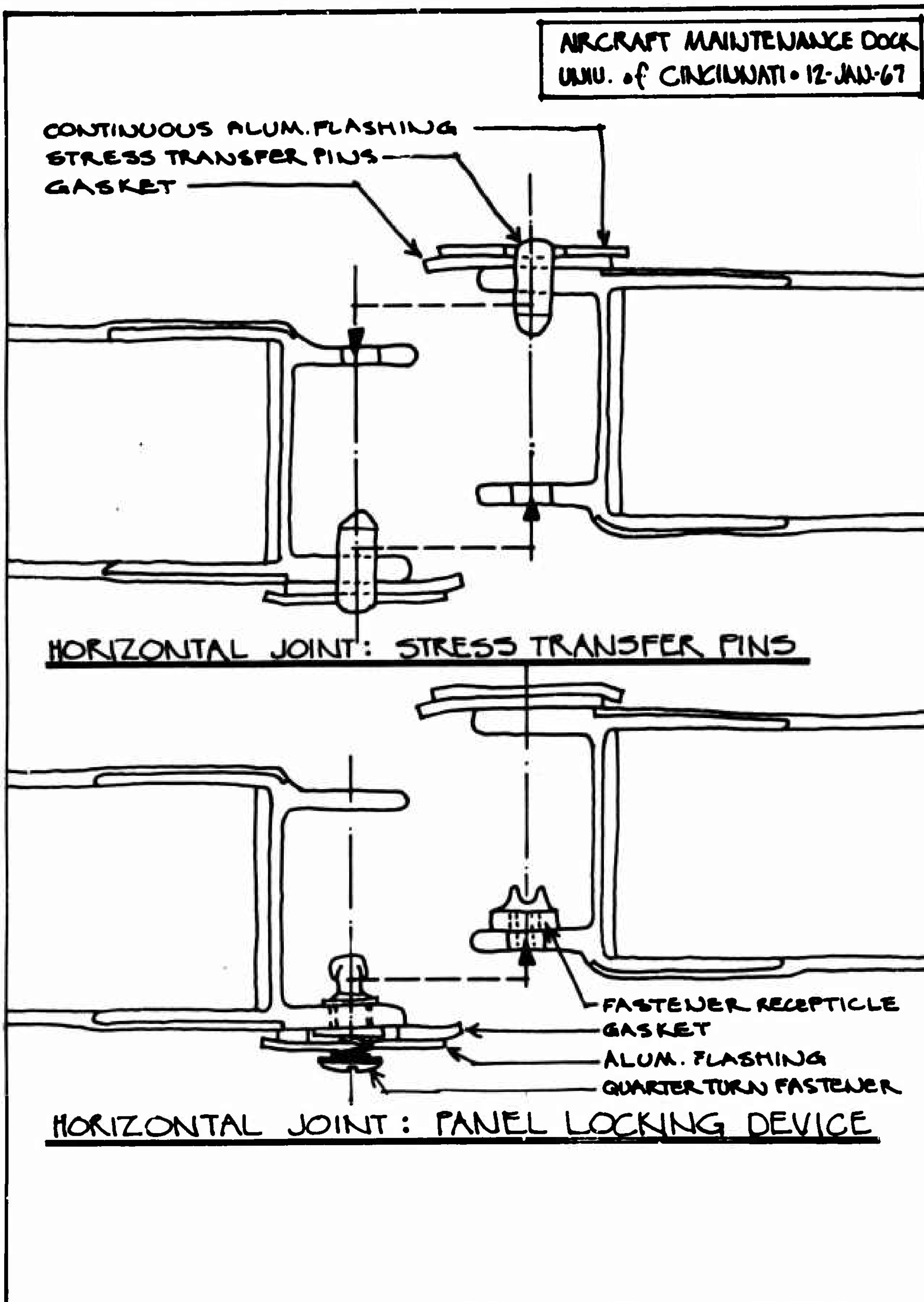


Figure 41. Horizontal Joint Stress Transfer Pins and Panel Locking Device

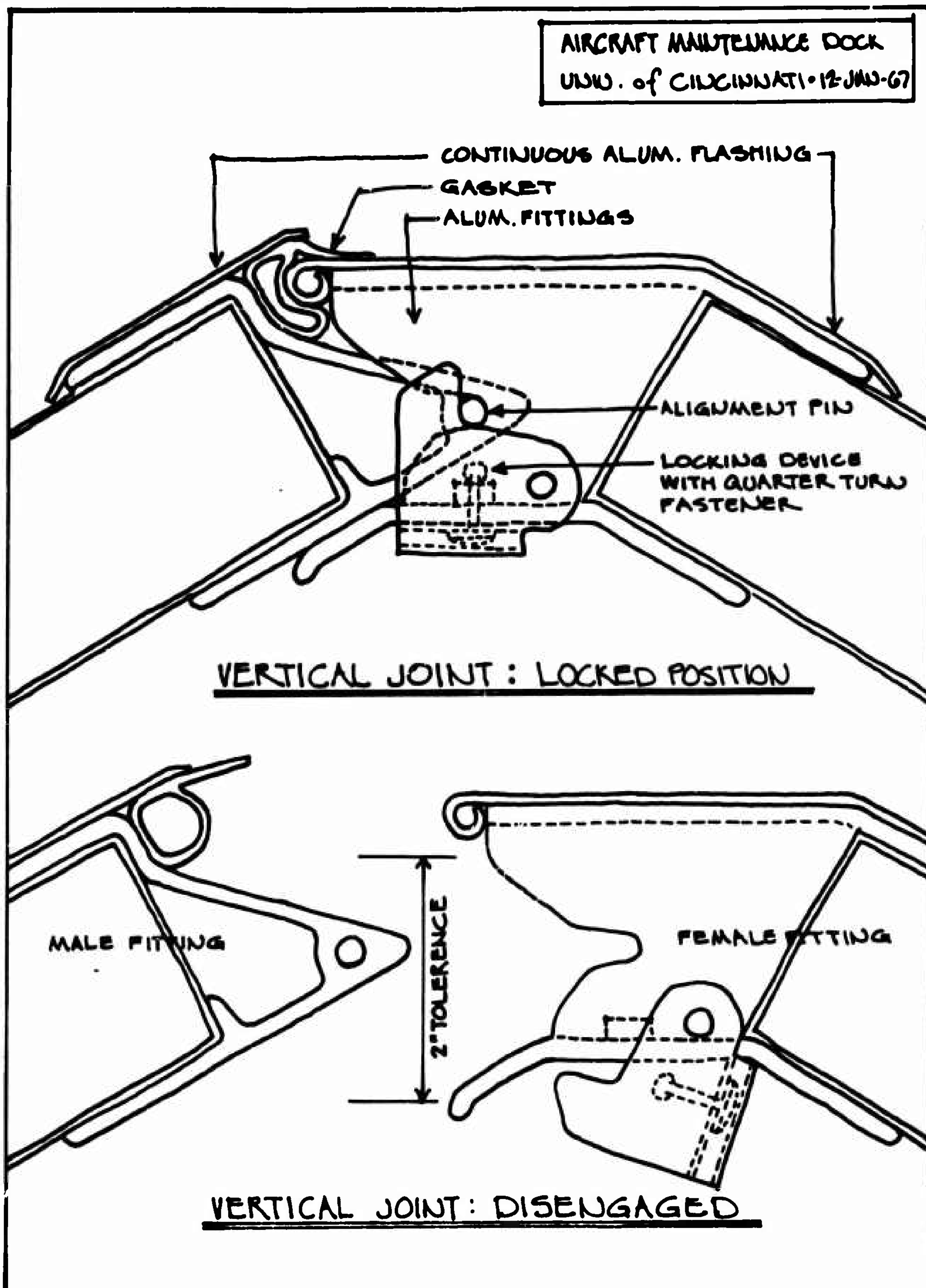


Figure 42. Vertical Joint: Locked and Disengaged

arch construction designed was not adequate to withstand the high concentrated loads of the cables (10,850 pounds each), a number of columns were chosen to be used behind such cables and the fabric is to take the vertical load of the cables. Figure 43 shows the location of six vertical beams suggested. They were designed to be pinned at both ends and the four middle ones to be moved to the sides for the opening. Column/arch fitting design is shown in Figure 44.

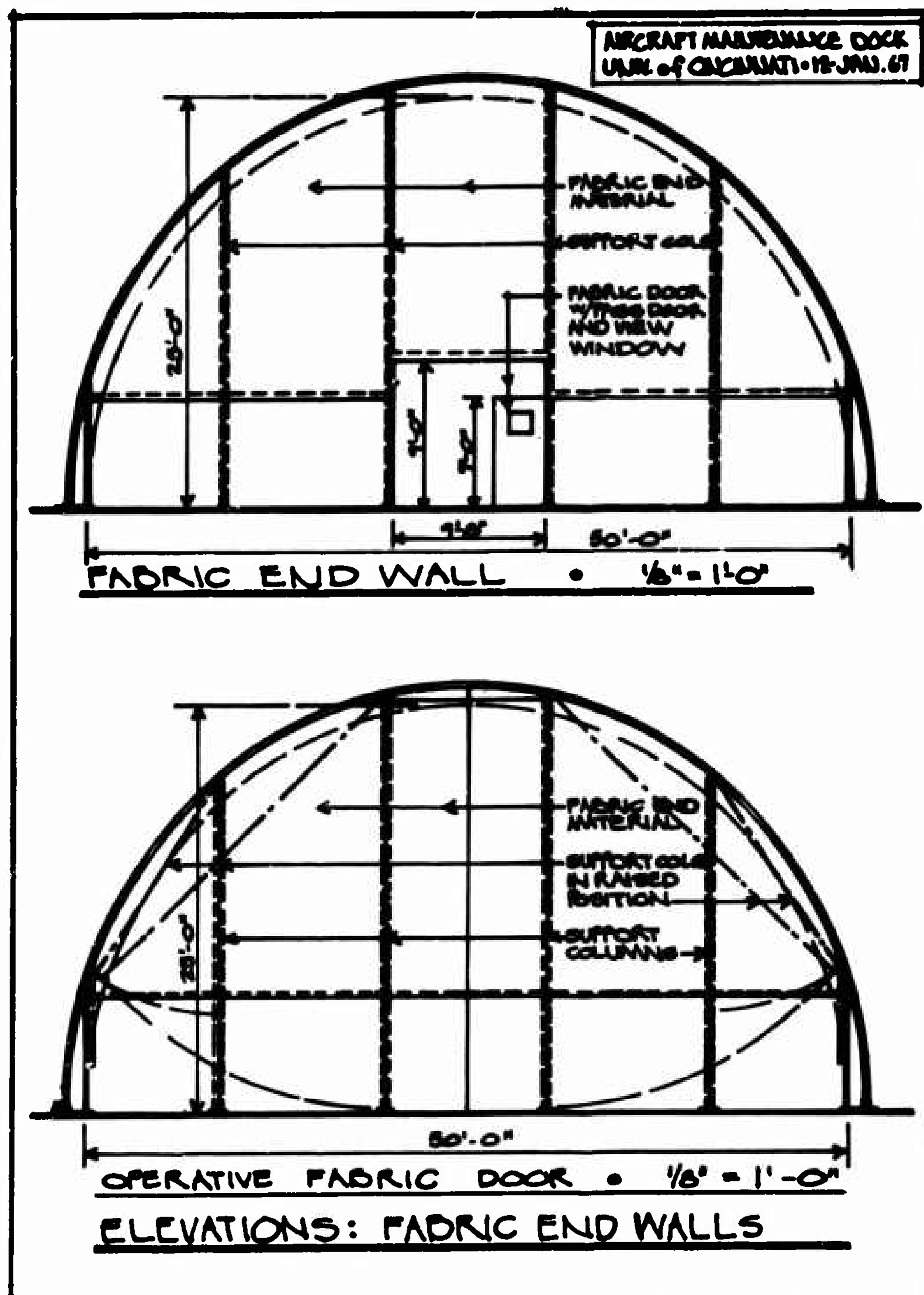


Figure 43. Elevations: Fabric End Walls

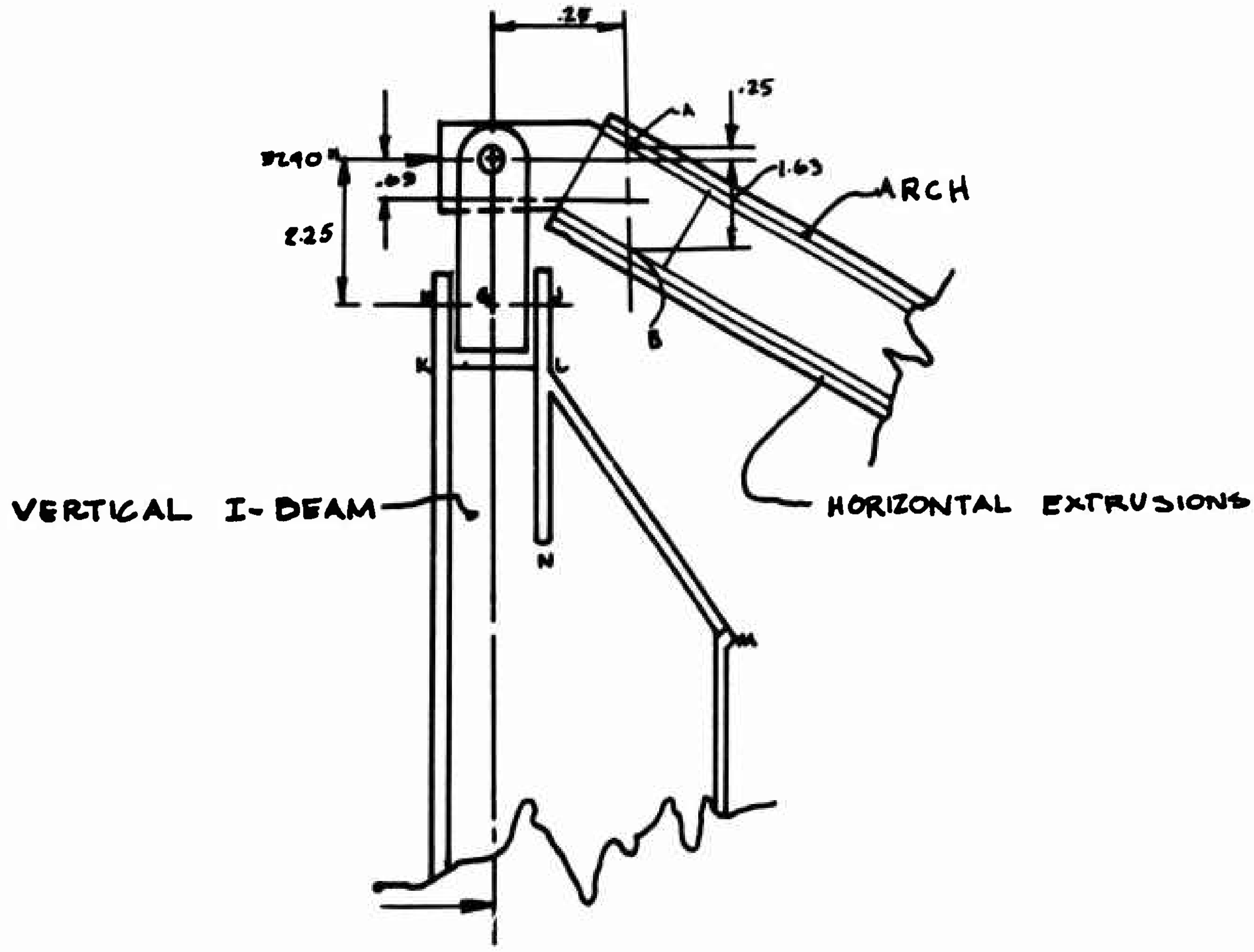


Figure 44. Fitting Arch to Vertical Beam

4. Base Pads and Arch Clamps

Since the arch modules were curved in section, appropriate clamping and locking mechanisms shown in Figure 45 were designed. The base bracket was designed as an aluminum sand casting and would form a load-bearing base pad capable of being secured to the ground by means of bolts or stakes.

5. Packaging

A number of packaging systems were investigated to accommodate pallets of specified sizes -nd panel modules. The systems considered were:

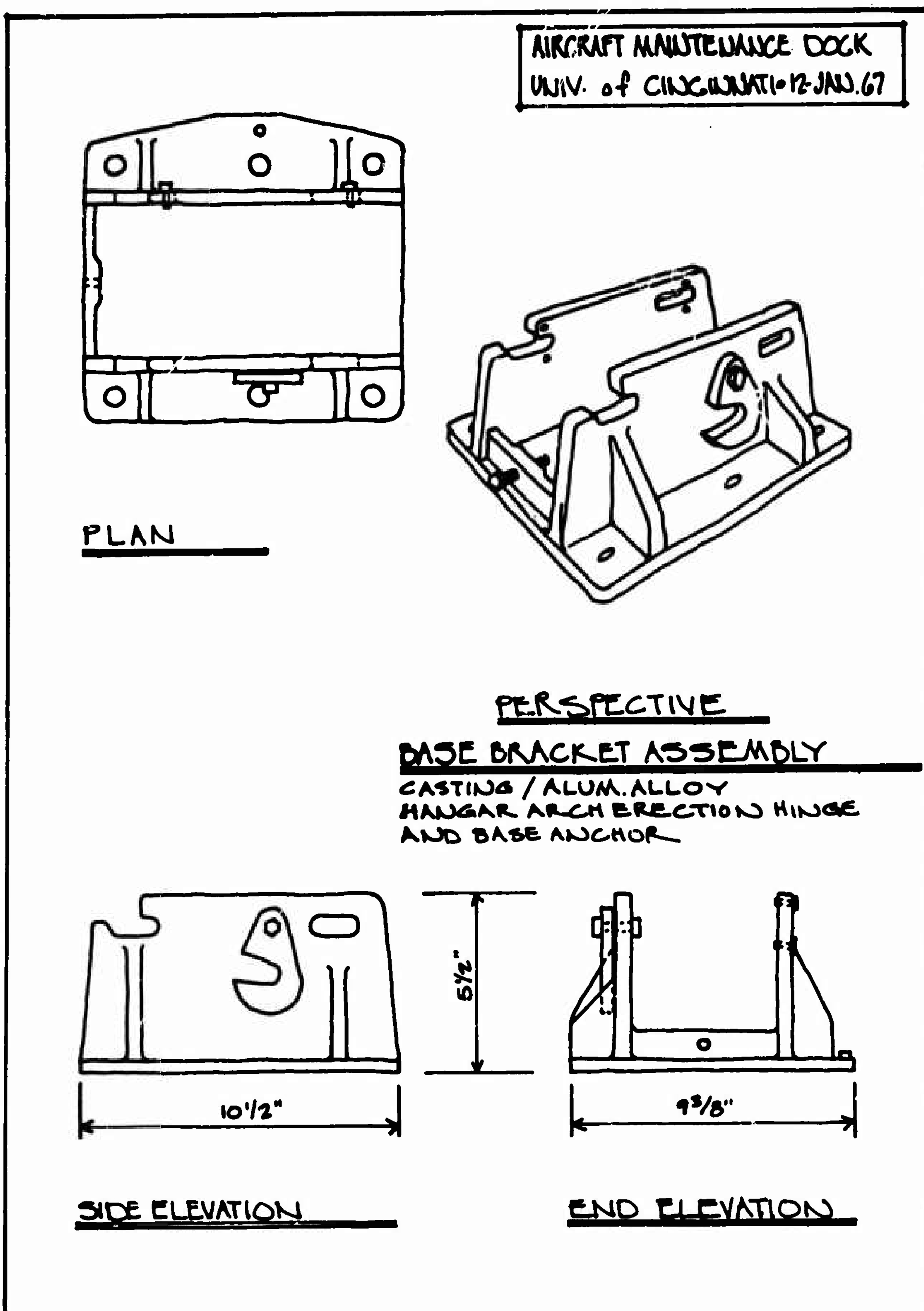


Figure 45. Base Bracket Assembly

a. Scaffolding System

This consisted of a shaped bed to accept the contour of the panels, a pair of support spars supporting the bed (capable of taking the "3G" load required), and four vertical rails acting as a combination of support legs and lateral and vertical load members with a number of stabilizing braces. A pair of Dacron or steel straps with an attached contour block was also used to hold the panels down. The straps had tension adjustment take-ups. The details of this system is shown in Figure 46. As a scaffolding system the frames would be used as shown in Figure 47.

The tubular members were 2" o.d. x .187" wall thickness of 6061-T6 aluminum alloy.

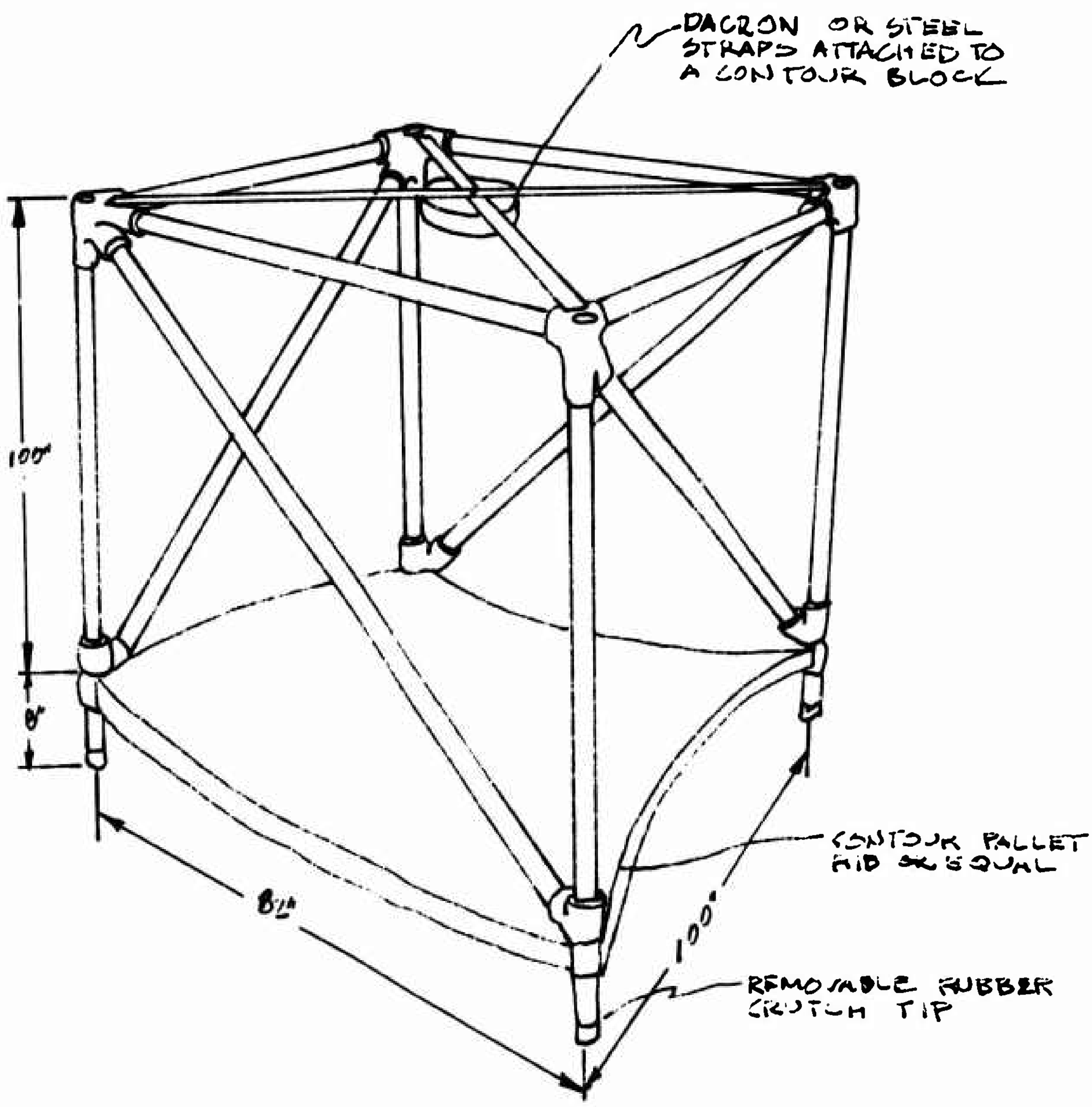


Figure 46. Modular Erection Pallet

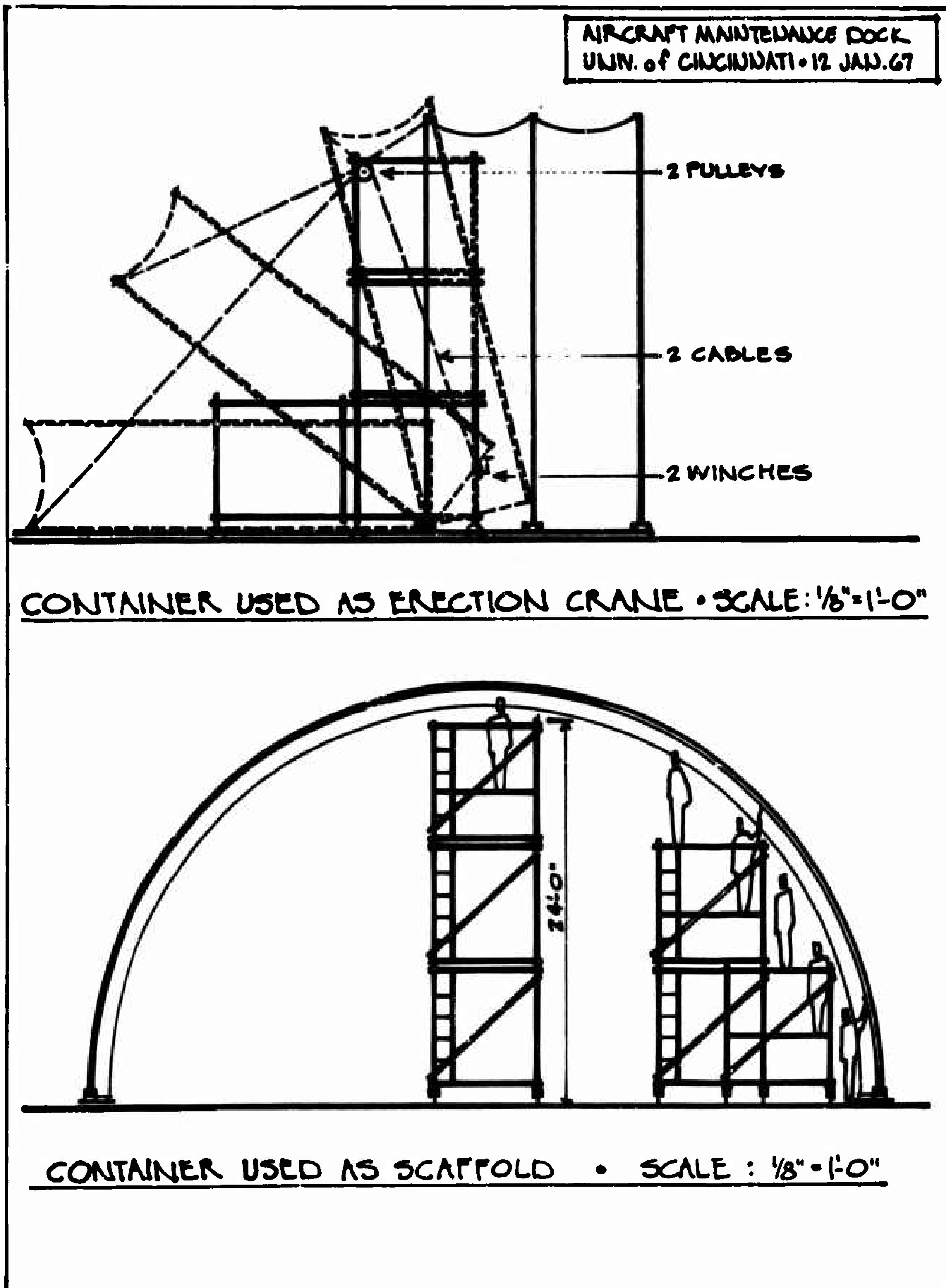


Figure 47. Container Used as Erection Crane

b. Minimal Pallet Concept

In this concept two aluminum spars and rails contoured to the shape of the panels were used as supporting bed, and steel or Dacron strapping was used to hold the panels down. Masonite or equivalent material was used at sides as protective elements for the panels. Details of this concept are shown in Figure 48.

4" x .180 structural channels, 6061-T6 aluminum alloy was used for spars.

The weight of each pallet = 184 pounds.

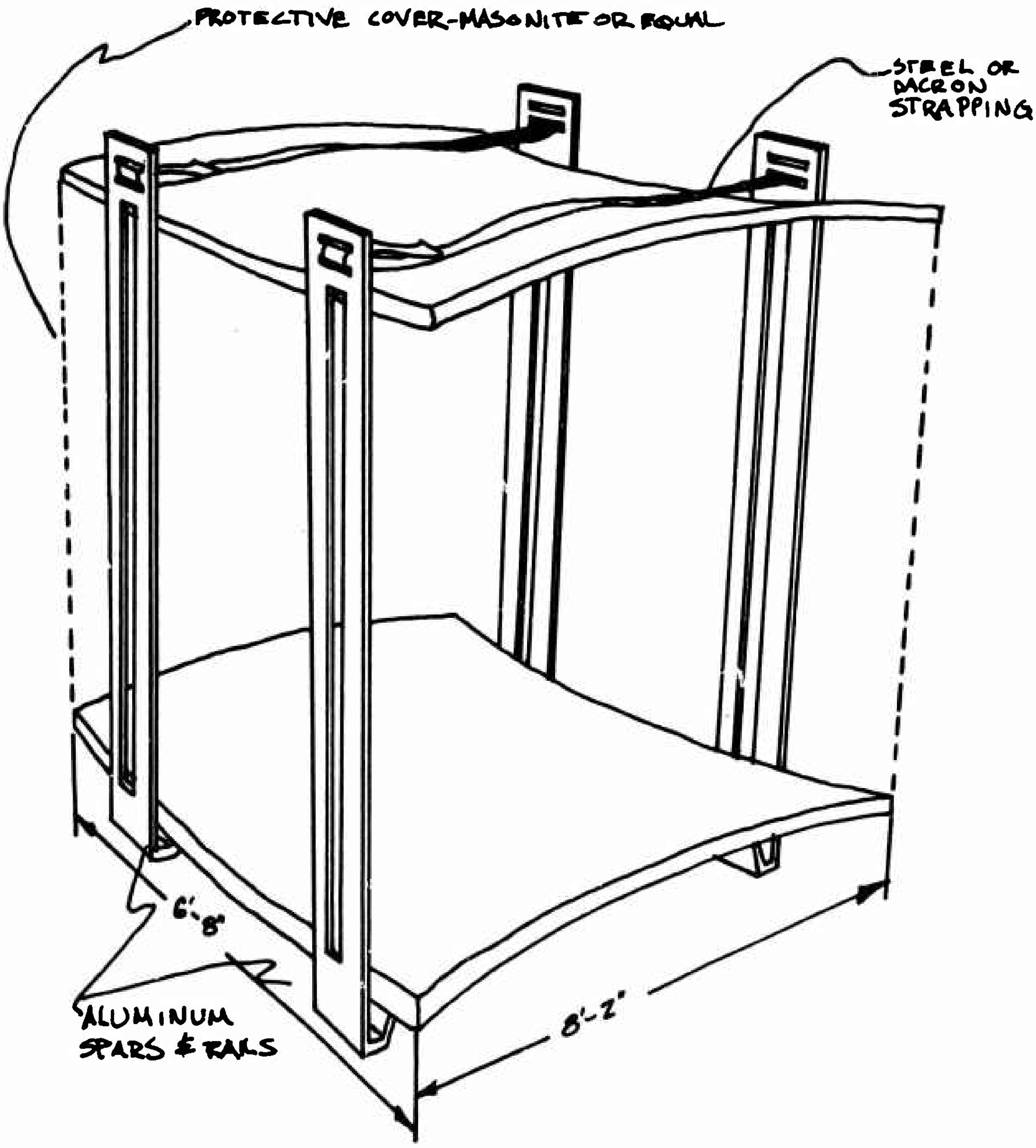


Figure 48. Minimal Pallet Concept

c. Wooden Module Pallet

This consisted of a base made of wooden ribs and surfaced with 3/4" plywood to form the contour of the panels and a number of vertical wooden or aluminum framing members to form an enclosed pallet. Steel or Dacron strapping was used for enclosing and securing the container. There were two versions of this concept, one with all wooden parts and another with wooden base rib and aluminum tubing for enclosing the sides. The details of these two are shown in Figures 49 and 50. The weight of each pallet = 160.5 pounds.

Structural analysis was carried out for all three types to withstand the following loads per pallet:

Vertical	3 x G	= 9410 pounds
Lateral	1.5 x G	= 4706 pounds
Forward and aft	1.5 x G	= 4706 pounds

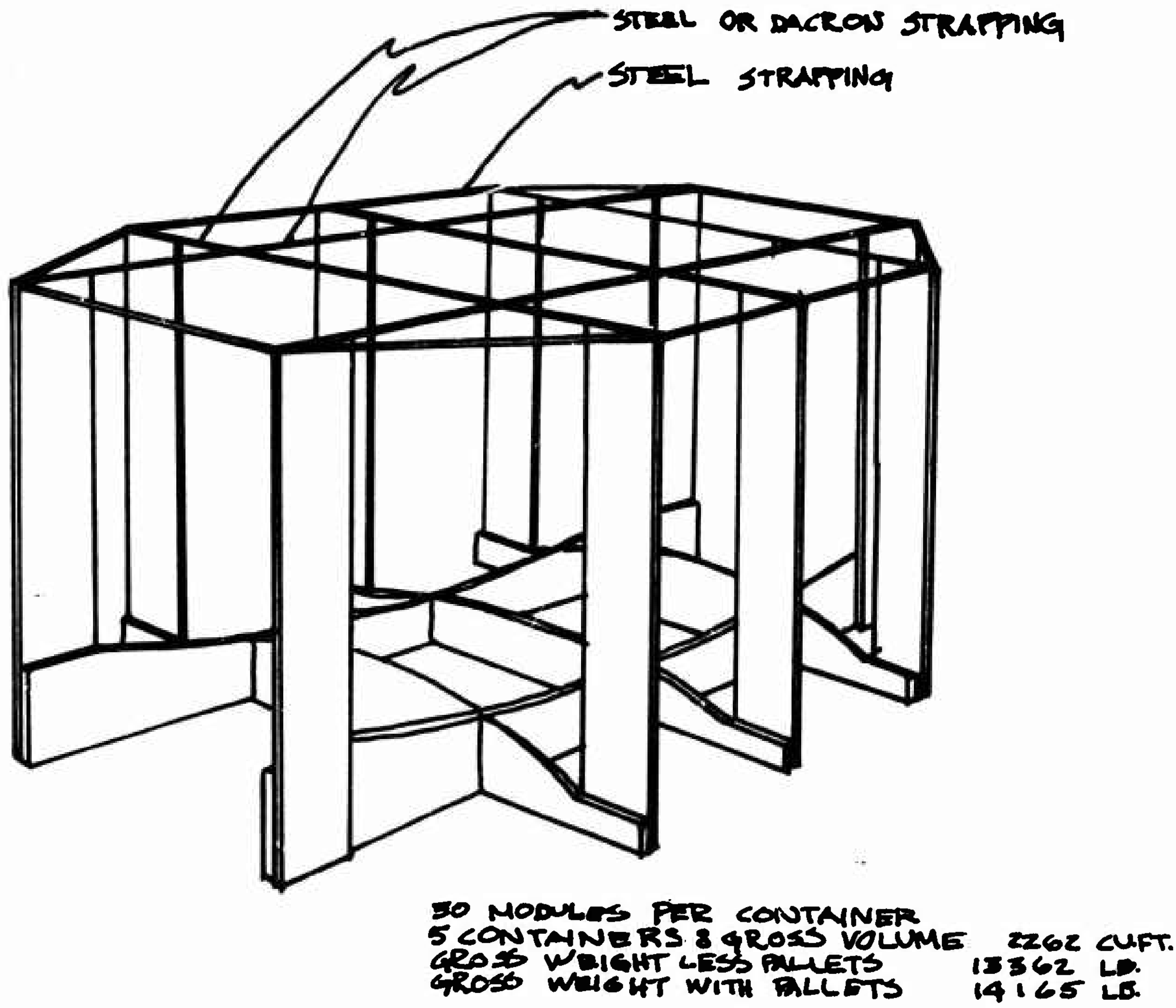


Figure 49. Module Pallet, Wood

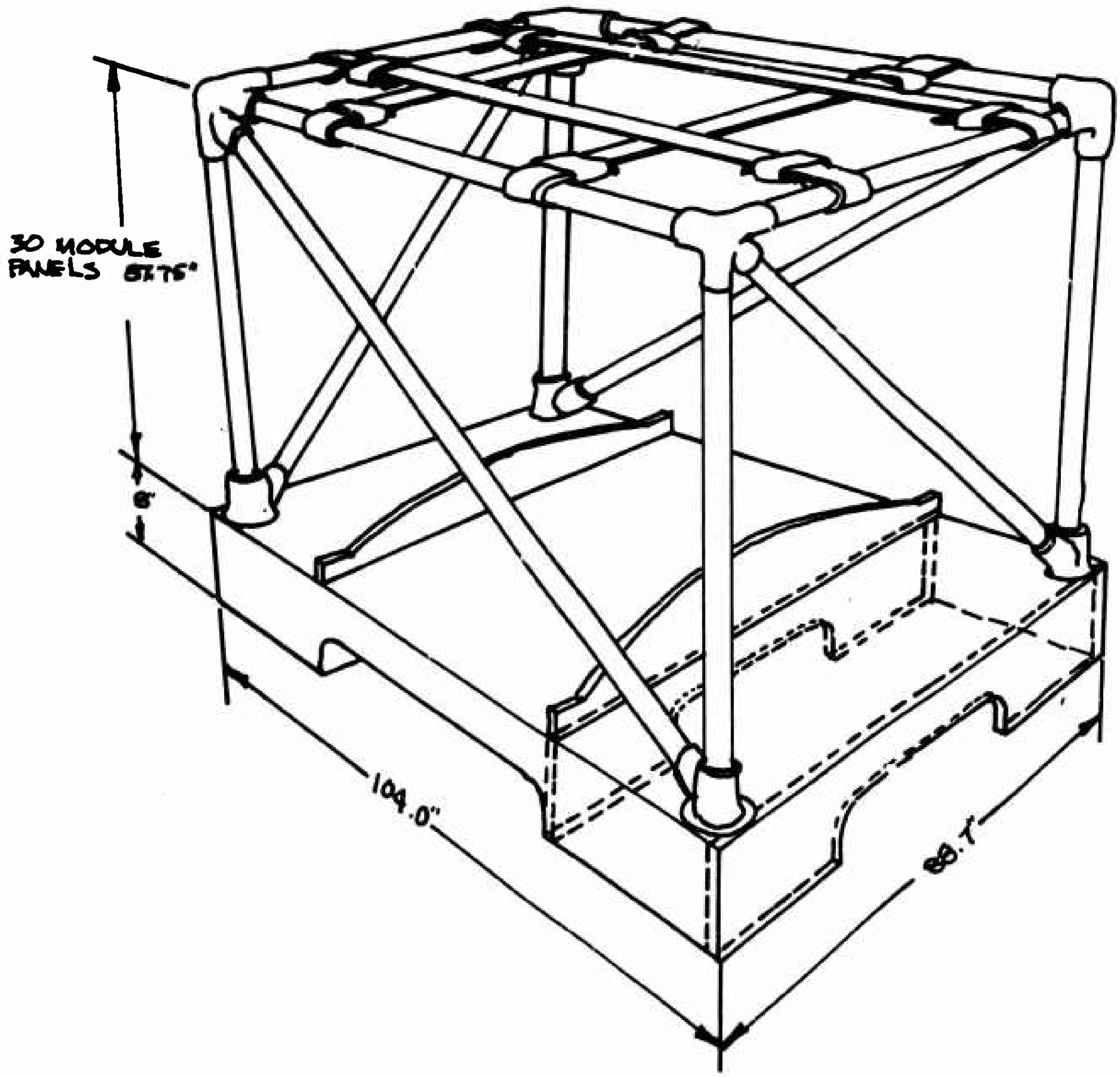


Figure 50. Module Pallet, Aluminum

G. SUMMARY OF DATA

Following is the statistical information on the double curvature concept hangar in the form reflected by final drawings prepared by the Whittaker Corporation:

Packaged Volume:	1350 cubic feet
Erection Time:	150 man hours
Weight	18,400 pounds
Cost of a Complete Hangar:	$144,000.00

This cost estimate as of January 1967 was the most discouraging aspect of the program. At the time competitive bids were received on the collaborative engineering effort (III,C,pages 43 and 45) estimates of cost of a first unit hangar averaged approximately $55,000 among the several bids received.

After the subcontract was awarded and as the work proceeded, successive estimates of the cost of a hangar were requested and received. The estimates rose in the following sequence:

September, 1966 . . . . $76,000

December, 1966 92,000

January, 1967 144,000

The first and second increases resulted primarily from the determination that the modules would have to incorporate aluminum frames within the honeycomb sandwich and from the increasing complexity of the horizontal and vertical joint connectors resulting from more complete stress transfer analysis.

The third increase followed the fabricating and testing of a full scale double curvature module. Failure of the test panel in static test required further redesign and increased projected cost.

This pattern of projected cost increases had an important bearing on decisions reached at a design review January 12, 1967.

H. <u>FINAL EVALUATION, DOUBLE CURVATURE PROGRAM</u>

A meeting was held at Headquarters, Tactical Air Command, Langley AFB, Virginia on 12 January 1967. The University presented the current state of development of the hangar program and a thorough discussion followed. The double curvature fiberglass panel concept was generally conceded to be more complicated than desirable. Much of the apparent simplicity of the initial studies had been lost in the detailed engineering and analysis effort of the preceding several months. This complexity was, for the most part, a result of the requirement that the hangar resist 90 mph winds.

Plans for building a full size test arch and a full size hangar at this time were set aside, and, via an Air Force RFP dated 6 February 1967, studies of improvements of the existing concept and development of several new designs based upon reduction of the wind load requirement to 65 mph winds were requested. A proposal covering this work was submitted to the Air Force on 27 February 1967.

One other point should be brought out at this time. A tabulation was made by the contractor as to the impact on critical statistics of the double curvature concept hangar of the elimination of the required rigid fixed end wall. This had been a basic requirement since the initial statement of work.

The following reductions would be made possible if the rigid end wall were replaced by a fixed fabric end wall:

Weight:	20% reduction
Erection Time:	10% reduction
Packaged Cubage:	17% reduction
Unit Cost:	19% reduction

Especially significant here is the fact that in packaging the hangar on 463L system pallets, the retention of the rigid end wall made it highly improbable that the structure could be packaged on the five pallets available in loading a C-130 aircraft to capacity. Substitution of the fixed fabric end wall assured capability of shipping one complete hangar per C-130.

IV

REVIEW OF NEW CONCEPTS

The impact of reducing the wind load design requirements from 90 to 65 mph was investigated. Significant cost, weight, cubage and erection time improvements were the goals.

Before new concepts were considered, a study was made to investigate possible improvements on the double curvature concept resulting from the relaxed structural requirements. It was found that the panel core thickness would reduce from 1-3/4" to 1.3". However, little significant change in fiberglass skins was anticipated. Due to the expense of fiberglass skins, tooling, and special handling required, small cost reduction could be anticipated.

It became evident that largest cost savings could be achieved by the replacing of fiberglass with aluminum facings. Since the double curvature configuration would necessitate that each aluminum skin be stretch formed and consequently make the overall cost prohibitive, several new hangar concepts were generated.

A. SINGLE CURVATURE ALUMINUM SKIN CONCEPT

The first redesign consideration for the reduced wind load conditions was to eliminate the double reverse contour of the basic panel module in favor of a single curvature module of 25'-0" internal radius. This configuration will necessitate a thicker panel due to the loss of inertia inherent in the double curvature panel. Even though this would increase the package volume, it would appreciably reduce the costs by producing a straight horizontal panel joint.

1. Hangar Size

The panel module remained 96" x 80" to be compatible with the 463L pallet system. A hangar would be made up of 12 arch sections with 10 panels per arch section. Thus the hangar size is 50' wide, 80' long and 25' high. (Figure 51)

2. End Walls

The openable and fixed fabric end walls are intended to hold a basic design similar to those of the double curvature hangar concept. The reduction in wind loading allowed for fewer columns at each end. Four columns are adequate for each end wall and are interchangeable. The column size is reduced from 8" x 5" to 6" x 4".

3. Panel Module

The single curvature modules are less efficient in bending

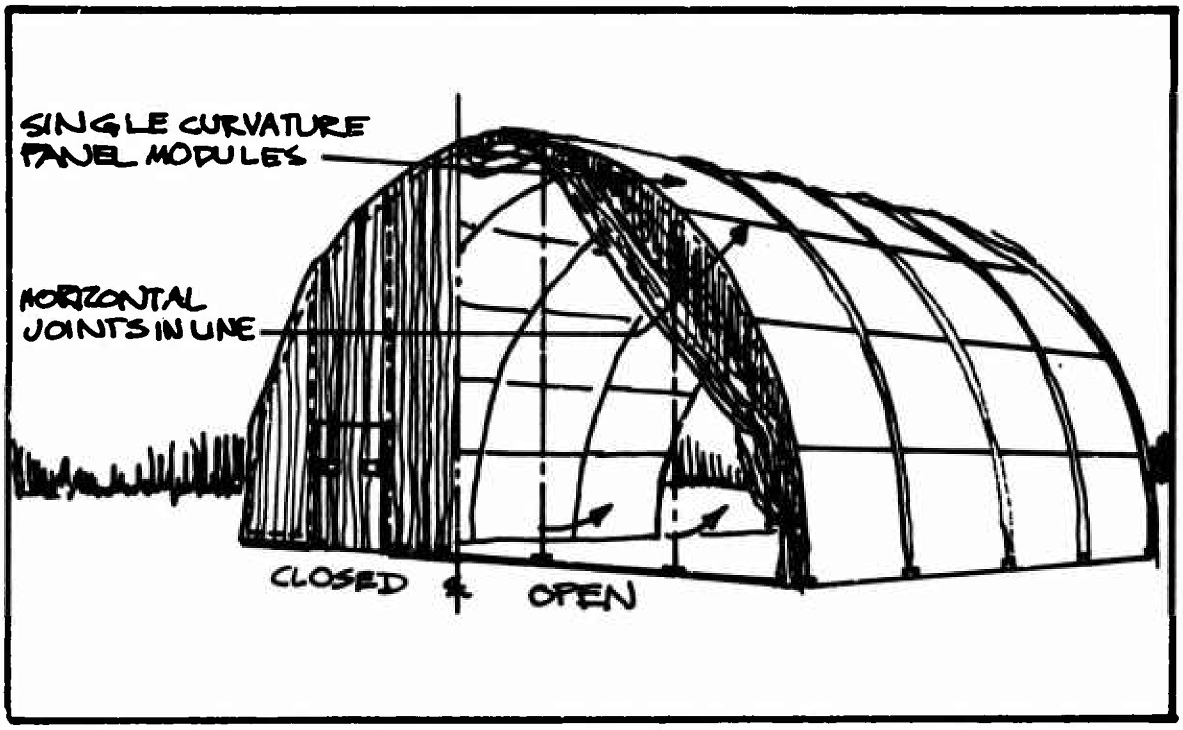


Figure 51. Single Curvature Concept

than the double curvature panels. This deficiency is, however, overcome by using a thicker sandwich section. In addition, the loading is reduced by a ratio of the square of the wind velocities: $(65/90)^2 = .523$. Thus, the bending moments at 65 mph are only about 52% of those encountered at 90 mph. This allows the use of .025 aluminum skin on a 3-1/4" deep paper core without any significant change in weight when compared with the 90 mph panels. (Figure 52)

4. Horizontal Joint

More pins are needed to transfer the bending moment because of the lack of curvature. Also, the bending moment is distributed evenly along the entire length of the horizontal joint rather than as a couple load at the extreme from the neutral axis such as exists on the double curvatured panels. This uniformly distributed bending moment (and shear) requires that the pins and fasteners be likewise uniformly spaced along the entire horizontal joint. (Figure 53)

5. Vertical Joints

Vertical panel edges (arch to arch connections) are joined by interlocking latches. The vertical latches can be spaced along the vertical panel edge members so as to line up with the end closure column fittings. This provides straight load paths for the drag loads induced by a 65 mph wind blowing along the hangar longitudinal axis. (Figure 54)

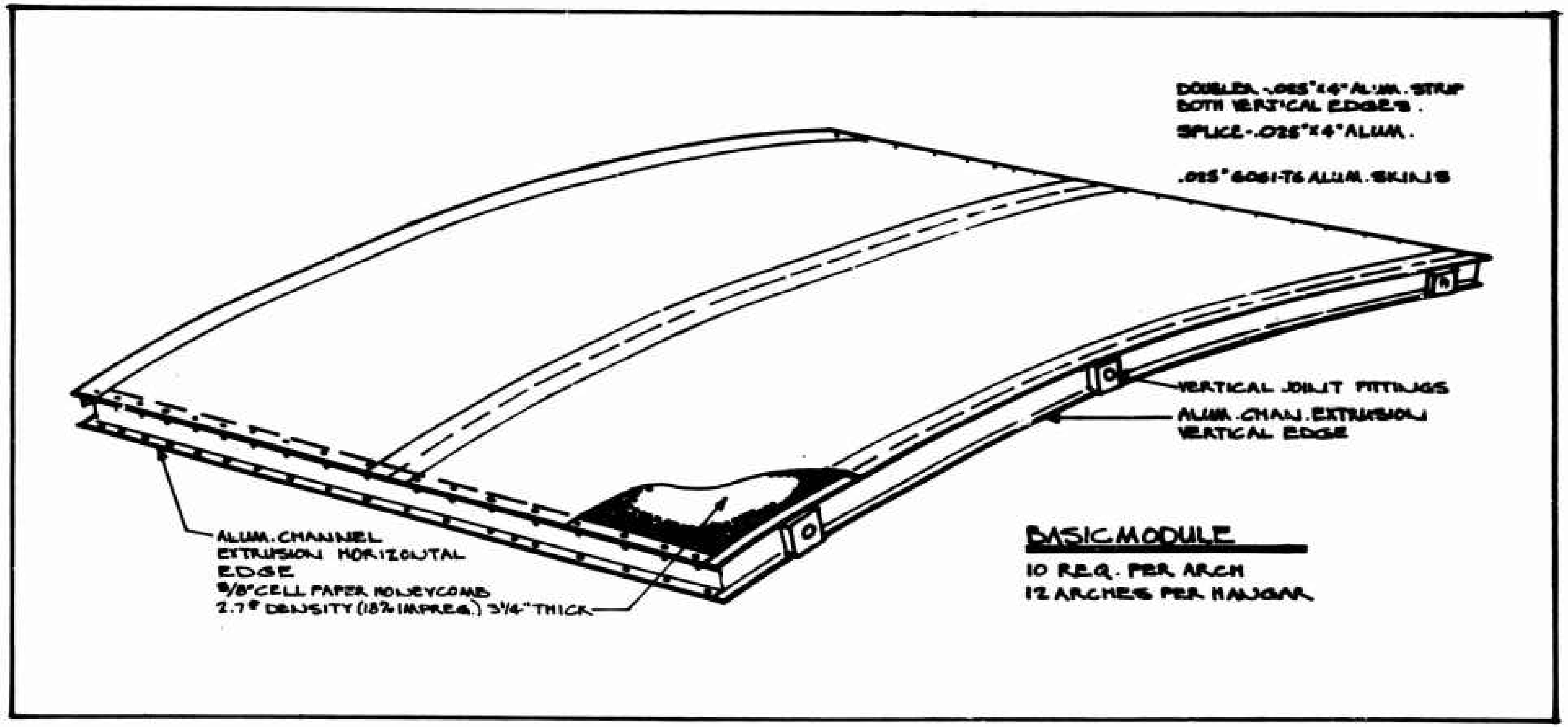


Figure 52. Single Curve Panel Module

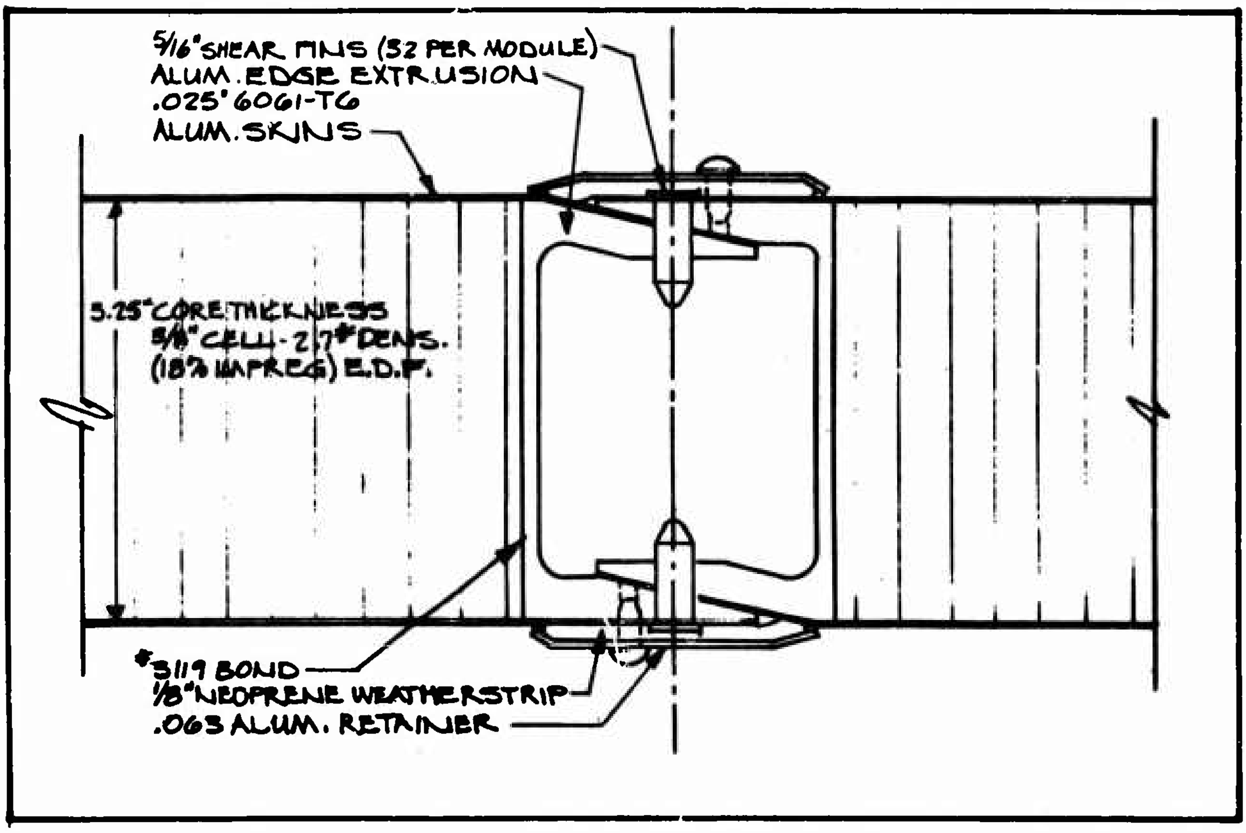


Figure 53. Panel Horizontal Joint

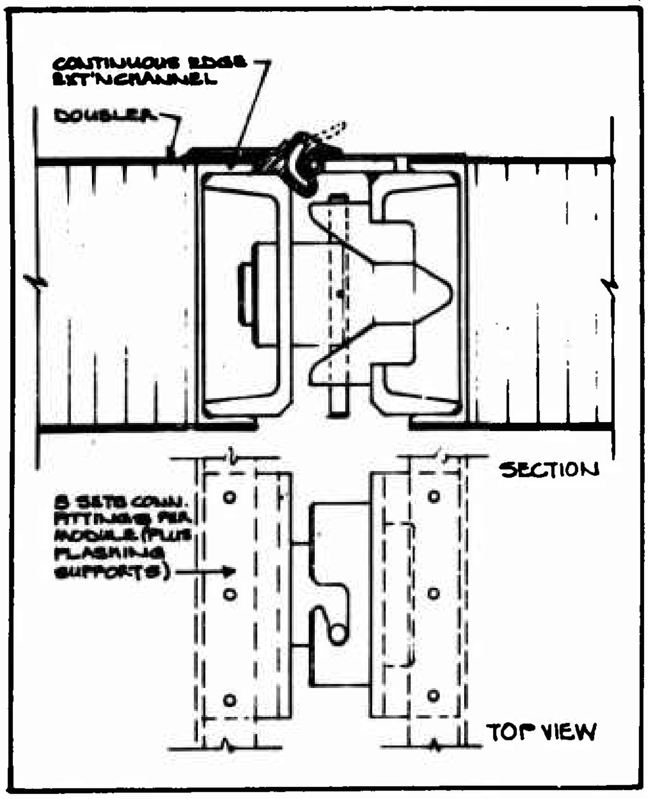


Figure 54. Vertical Joint

6. Base Pads

Base pad brackets are not as complex as required for the double curvature panels because there is no curvature in the horizontal panel edges. (Figure 55)

7. Erection

The erection procedure will remain the same as for the double curvature concept. To briefly recap, ten panel modules are assembled at ground level to form an arch with the end modules pinned to the base brackets. The assembled arch will then be raised into a vertical position approximately 1" from the adjacent positioned arch. The arch being raised will be checked for rough alignment against the mating arch and then moved horizontally 1" into its final position. Each base bracket will contain a pivot and guide pin arrangement.

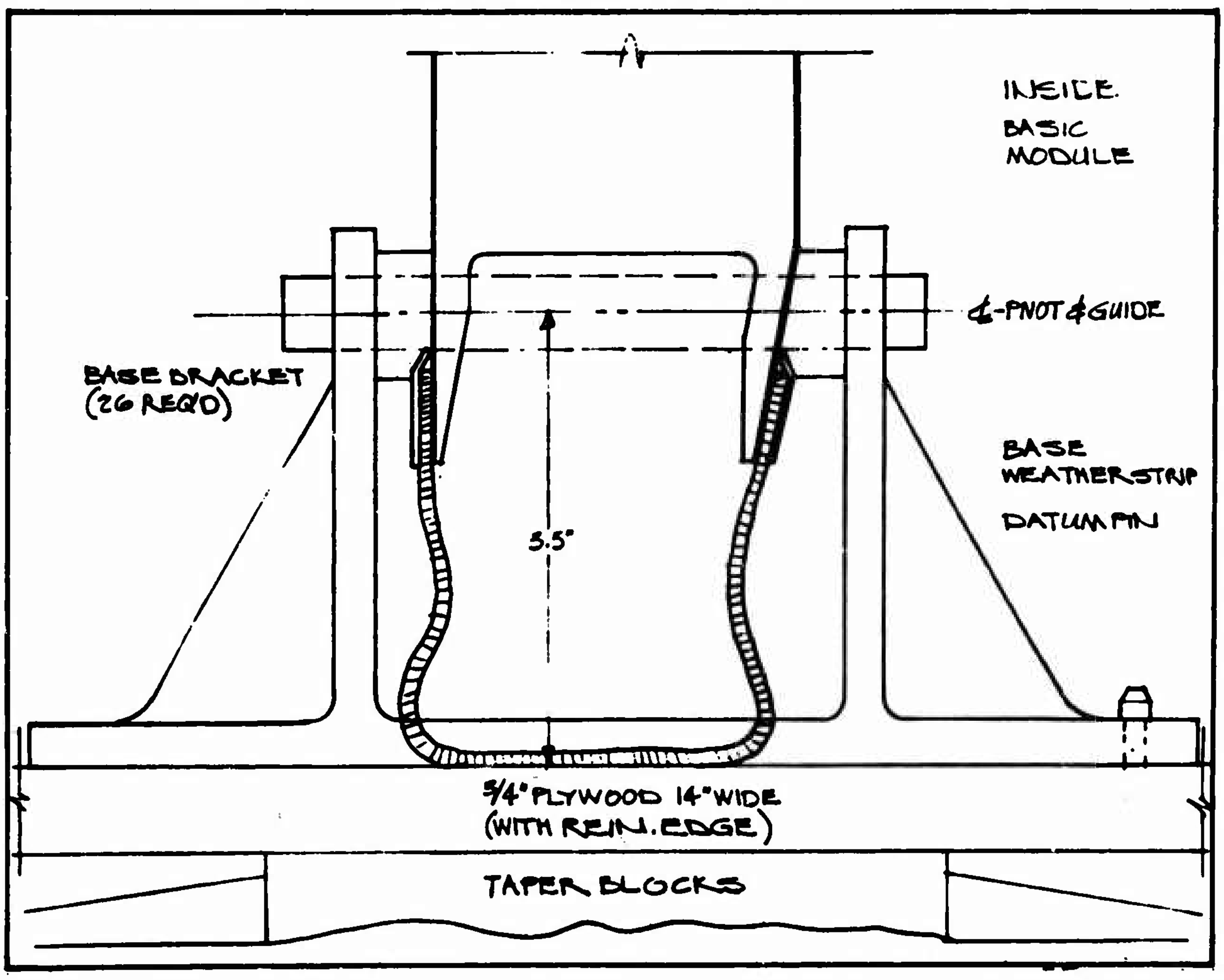


Figure 55. Base Pad

8. Supplementary Notes

A design very similar to the Whittaker Corporation single curvature concept was proposed by Goodyear Aerospace Corporation. The primary difference was that the panel skins were fiberglass instead of aluminum. Their panel was made up of 2" thick, half inch cell size 125 pound paper honeycomb core, .042 inch skins of fiberglass fabric laminate and aluminum close out extrusions. Preliminary cost estimates far exceeded the cost goal. However, some design details generated by this effort were of interest. The vertical (arch to arch) panel edges are joined by interlocking extrusions that have integral seals. (Figure 56) Closing of this joint depends upon raising the arch being erected and lowering it to interlock with the previously erected arch. (Figure 57) This raising and lowering operation requires a jacking device. A device was proposed that could be moved from arch to arch as required for erection. This reduced the impact of designing each base pad to perform this jacking operation. (Figure 58) As shown in this drawing, a bracket is bolted to the base arch panel and moves on rollers in order to overlap one arch over another. Bolting through these panels would require special panels and a means to seal the holes after erection. Therefore, another means of transferring the arch load to the jacking device would be desirable.

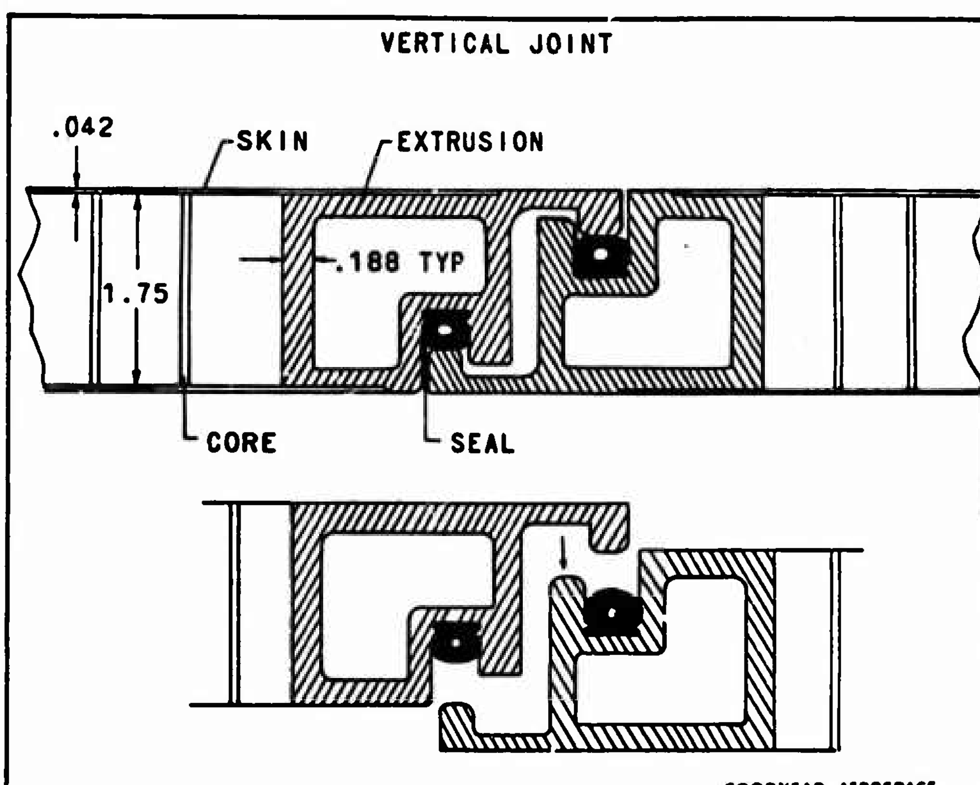


Figure 56. Vertical Joint

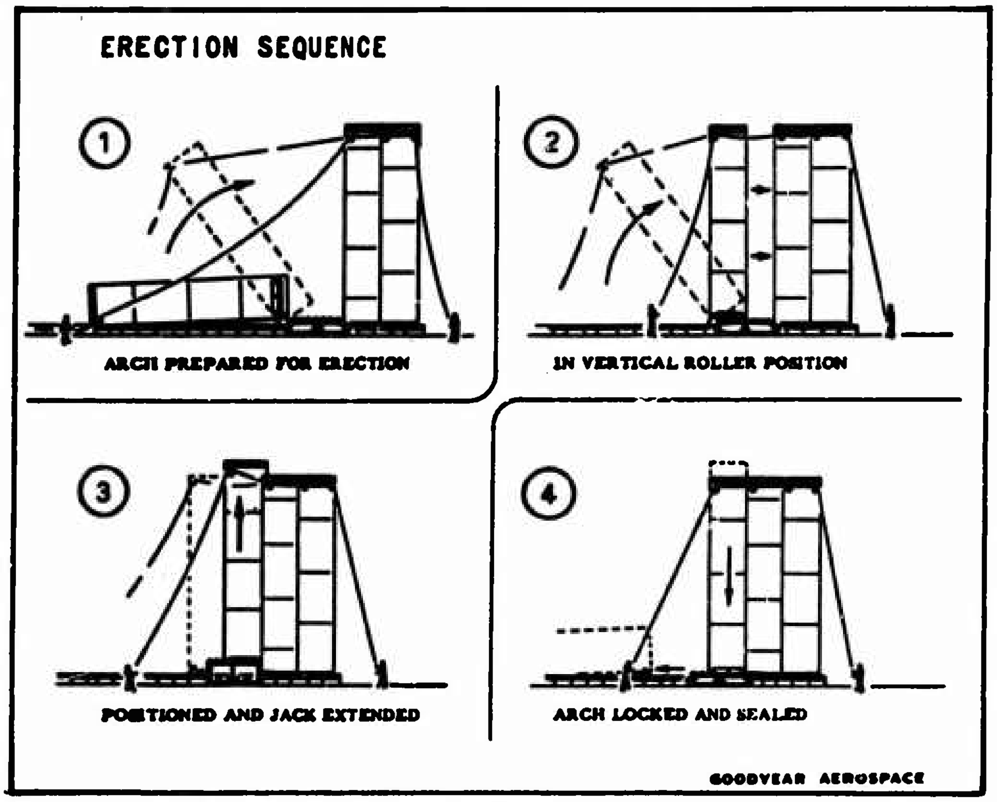


Figure 57. Erection Sequence

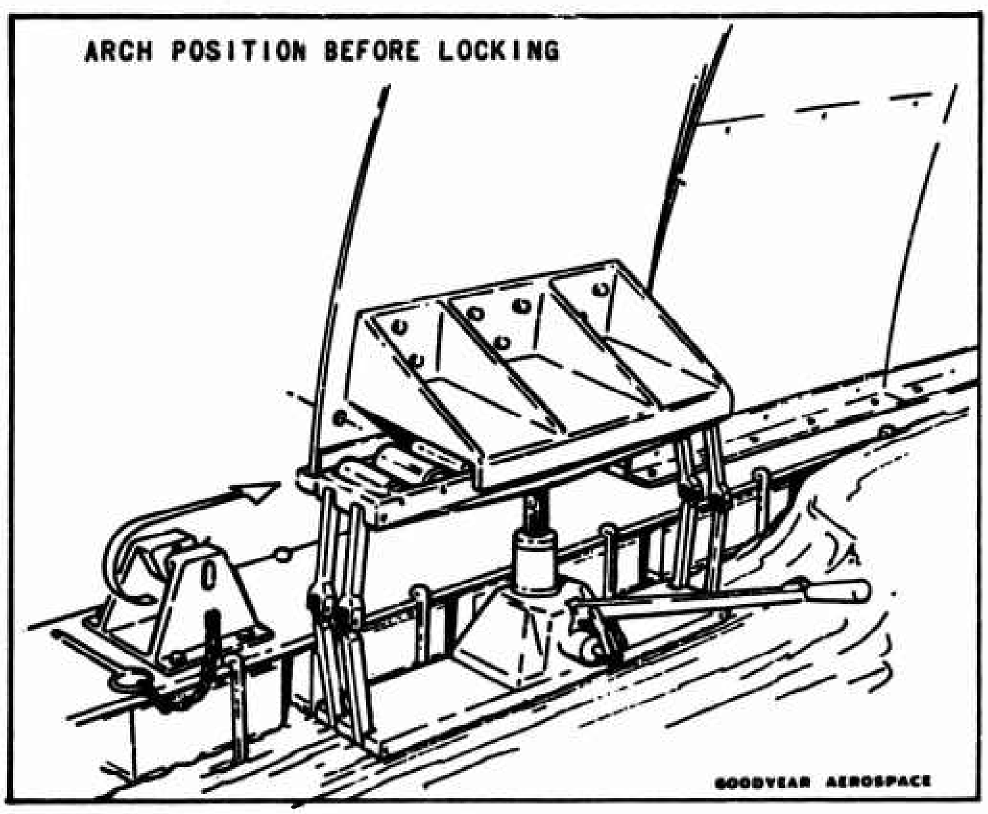


Figure 58. Jacking Device

Another concept was briefly studied by the Whittaker Corporation. This design embodies a V-shaped panel module in which no curvature is present. (Figure 59) This increases the basic moment of inertia (much like the double curvature panel) which enables a thinner core to be used with a resultant lower weight and smaller packaging volume than the single curvature version. In effect this exercise reopened consideration of Concept "D-1" discussed on page 33 and illustrated in Figure 33.

The V type panel has a similar weight and volume to the double curvature panel. However, initial analysis indicated that an increase in panel thickness is required at the V junction along the vertical center of the panel. A thicker sandwich construction in this area would cause considerable stacking problems as well as manufacturing difficulties.

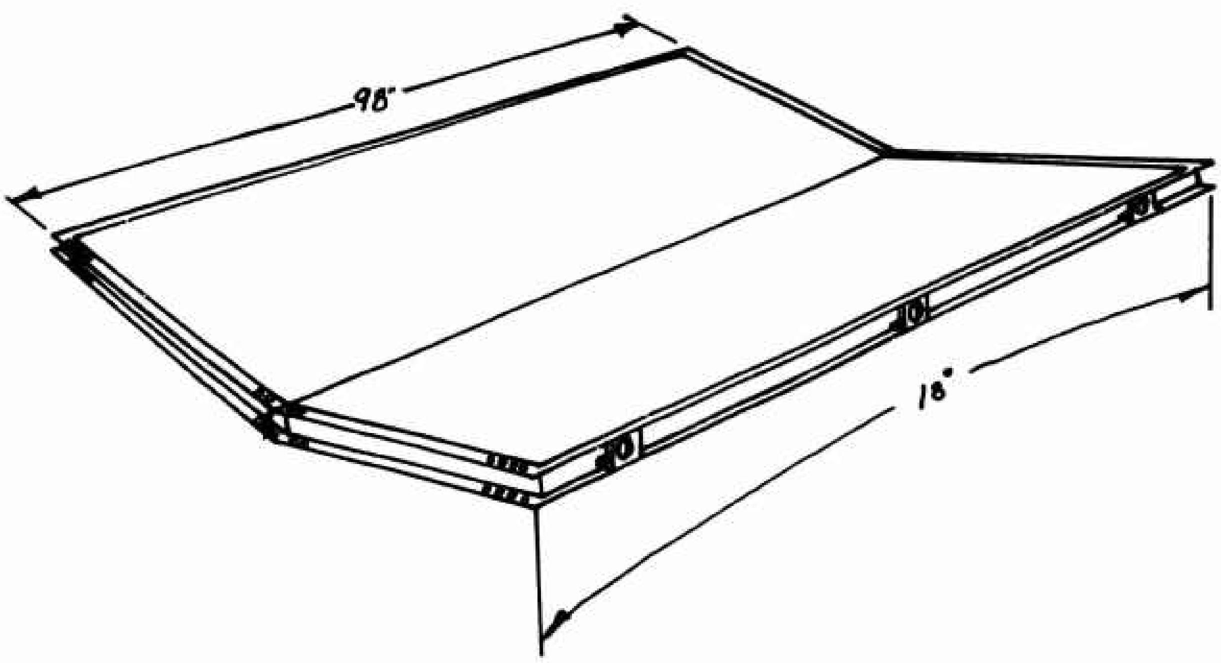


Figure 59. "VEE" Panel Module

B. DOUBLE BEND STRAIGHT PANEL CONCEPT

Efforts to reduce costs of the double curvature panels and high package volume of the single curvature panels without degradation to the high moment of inertia inherent with the double curvature panels led to the following design considerations:

1. Panel Module (Figure 60)

A panel that is straight in the erected vertical direction and double "bent" in the horizontal direction was designed. The resultant hangar configuration (Figure 61) is similar

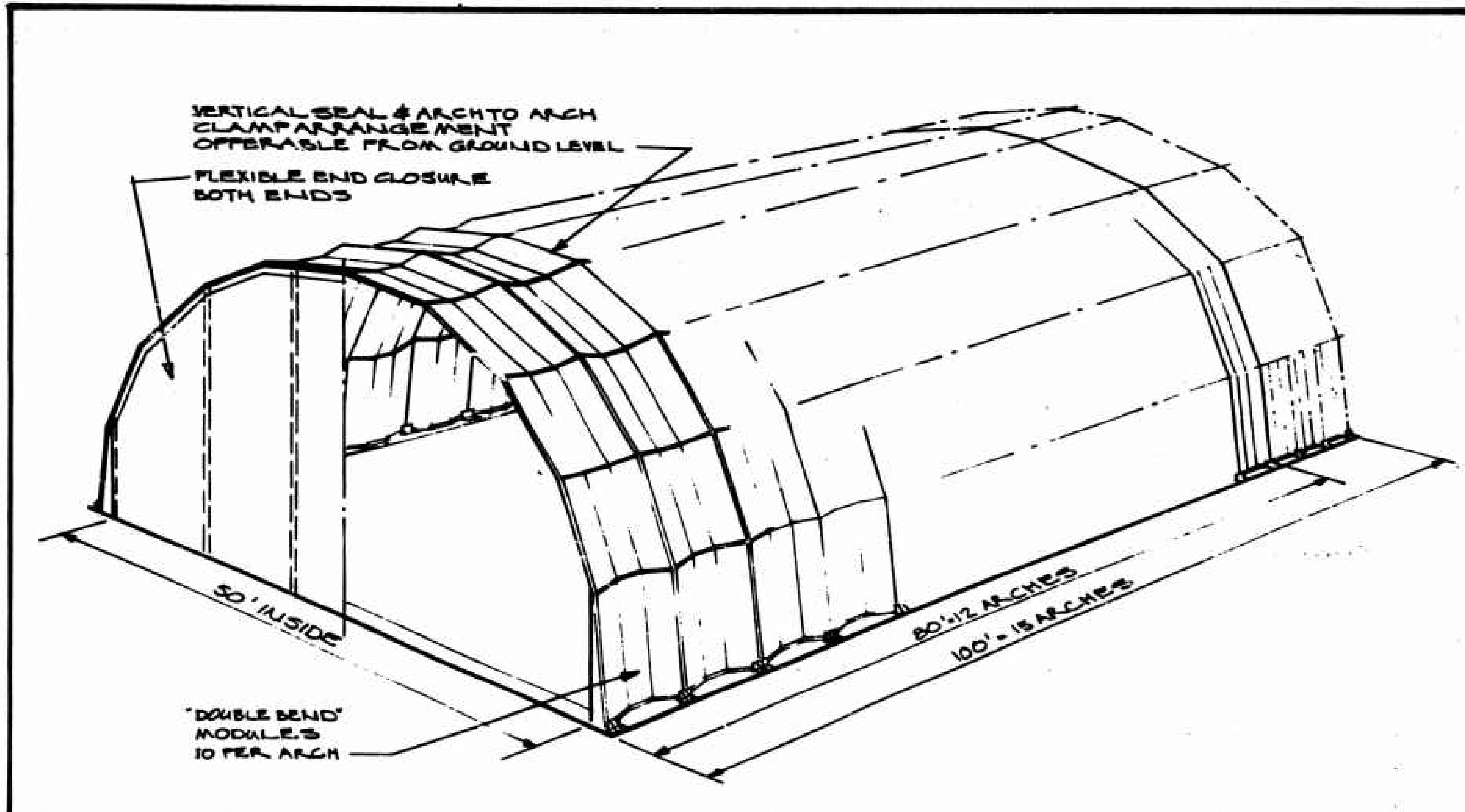


Figure 60. Double Bend Panel Concept

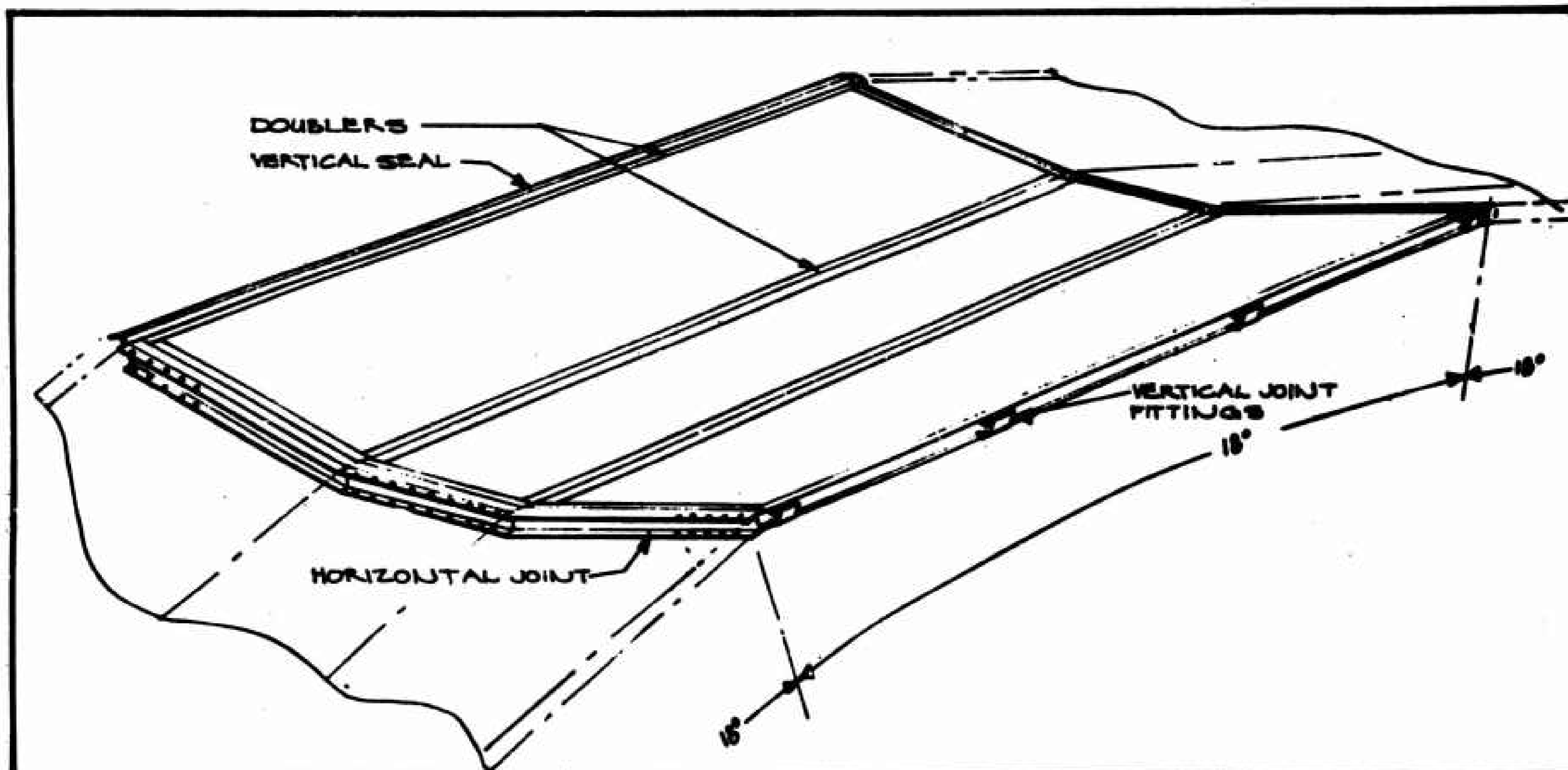


Figure 61. Double Bend Module

to the double curvature concept configuration. The ends are angled at 9° to form a complete arch when 10 modules are assembled. A preliminary stress analysis indicated that an overall depth of 14" would equal the double curvature panel moment of inertia, with .032" aluminum skins to resist a 90 mph wind load and .020 skins for a 65 mph wind. Doubles are required at the "bent" corners. The panel core is 1-3/4" paper honeycomb for both wind load conditions.

2. <u>Vertical Joint (Figure 62)</u>

An arch to arch panel locking system was proposed that would enable all arch assembly and erection handling to be completed from ground level.

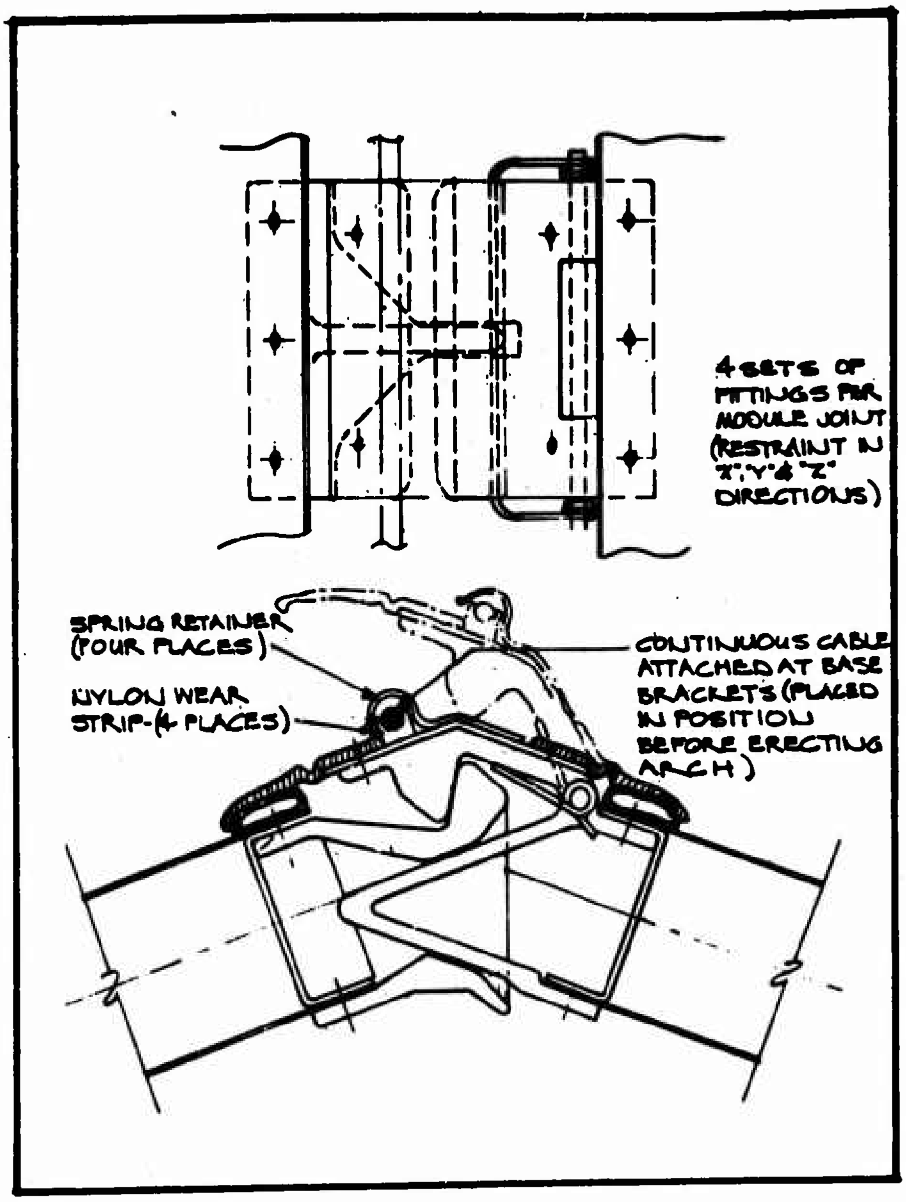


Figure 62. Vertical Joint

A continuous cable is installed (after the assembly of the modules at ground level) to the outside face of a flashing that is in turn attached to four spring-loaded fittings assembled to each module. The cable will then be loosely attached to the base brackets on each side. The arch will then be raised into the vertical position and moved horizontally into its final position against the adjacent erected arch. By applying tension to the cable, the flashing and seal will be pulled against the vertical edge and provide a weather seal. The aforementioned fittings serve also as a catch that will engage and restrain longitudinal movement.

3. Horizontal Joint (Figure 63)

The horizontal panel to panel joint is assembled by interlocking stress transfer pins and latching the quarter turn fasteners.

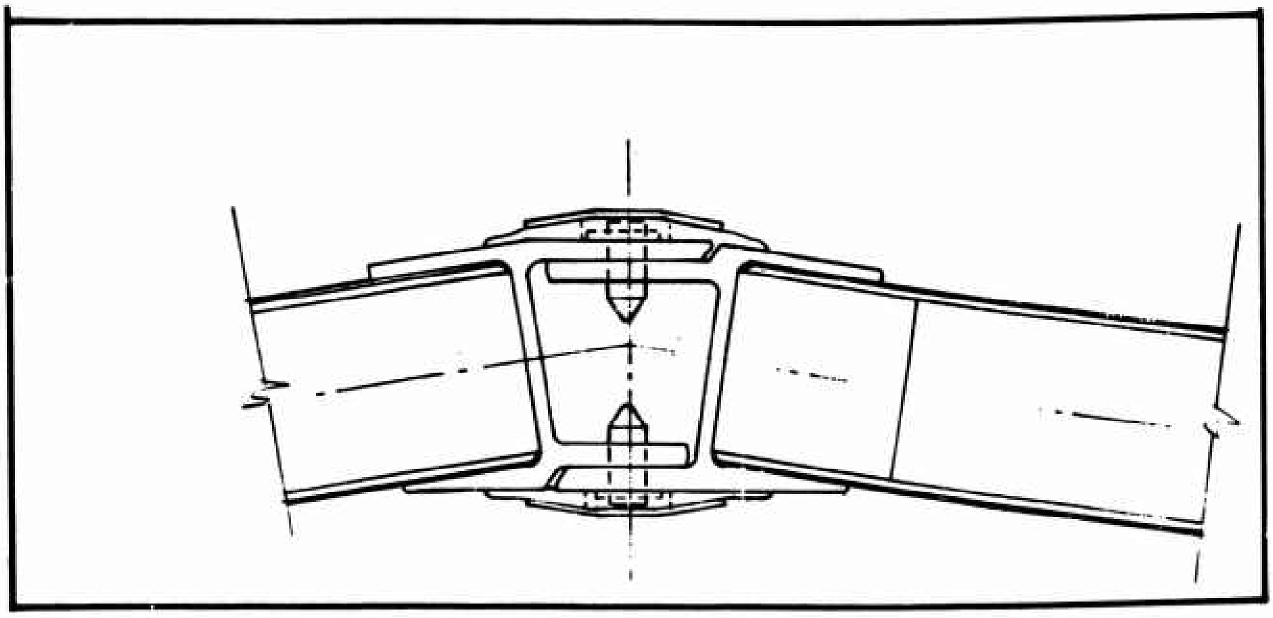


Figure 63. Horizontal Joint

4. Corner Weather Seal (Figure 64)

A method of weather sealing at the four corner panel to panel and arch to arch joints was porposed. The vertical seal overlaps a portion of the horizontal seal.

C. PANEL WITH INTEGRAL RIB CONCEPT

Concepts discussed prior to this one have been basically "shell" types of structures - that is, the panel modules when assembled form a smooth, continuous thin shell arch configuration which provides the structural integrity of the hangar structure.

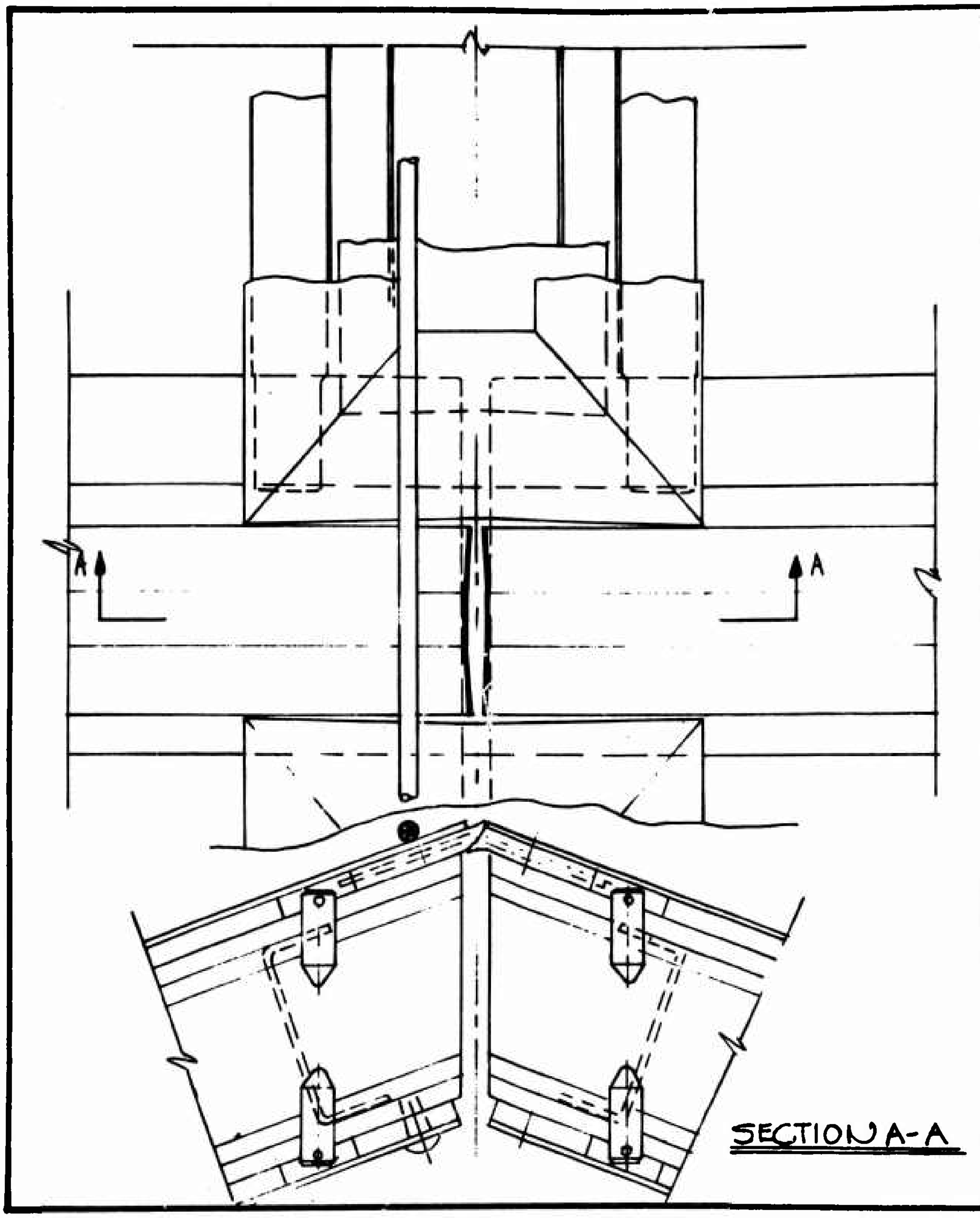


Figure 64. Corner Weatherseal

These "shell" type panel modules present two basic problems. First, they require elaborate manufacturing controls to ensure structural integrity. This tends to boost costs. Second, their thickness required to provide an adequate moment of inertia results in excessive volume required for packaging.

This "Panel Concept" represents an investigation of a system involving ribs and infilling panels. The ribs are the primary structural elements and the panels simply span from rib to rib. The panels then can be less than 1" thick which appreciably reduces package volume for storing and shipping purposes.

1. <u>Panel Module</u>

In this concept the structural ribs are integral with the panel modules. (Figure 65) The ribs are contoured in such a way as to nest to reduce stacking height thus achieving a package mode volume appreciably less than the shell type panel concepts. The ribs are extruded aluminum and lock together with interlocking hinges. The panel portion has aluminum skins over a 5/8" paper honeycomb core.

2. <u>Erection</u>

Ten panel modules assemble to erect an arch of 50' span and 25' height. Twelve arch sections make up a barrel vault 80' long. (Figure 66)

3. <u>Vertical Joint</u>

The vertical (arch to arch) joint is sealed by the interlocking of the panel side structural ribs as an arch is raised into a previously erected arch. The structural rib on one side of each panel module is smaller than the rib on the other side such that when they interlock and seal the flat portion of each adjacent panel is in the same plane. (Figure 67)

4. <u>Supplementary Note</u>

Preliminary analysis indicated that it would be difficult to provide enough stiffness in the panel structural ribs to prevent bending of rib flanges when subjected to design load stresses.

Shear flow in the proposed rib shape would cause the rib to open and deform. (Figure 68) An elaborate locking mechanism that would have to be attached to the underside of the erected arch would have to be used to form a closed stable arch rib frame.

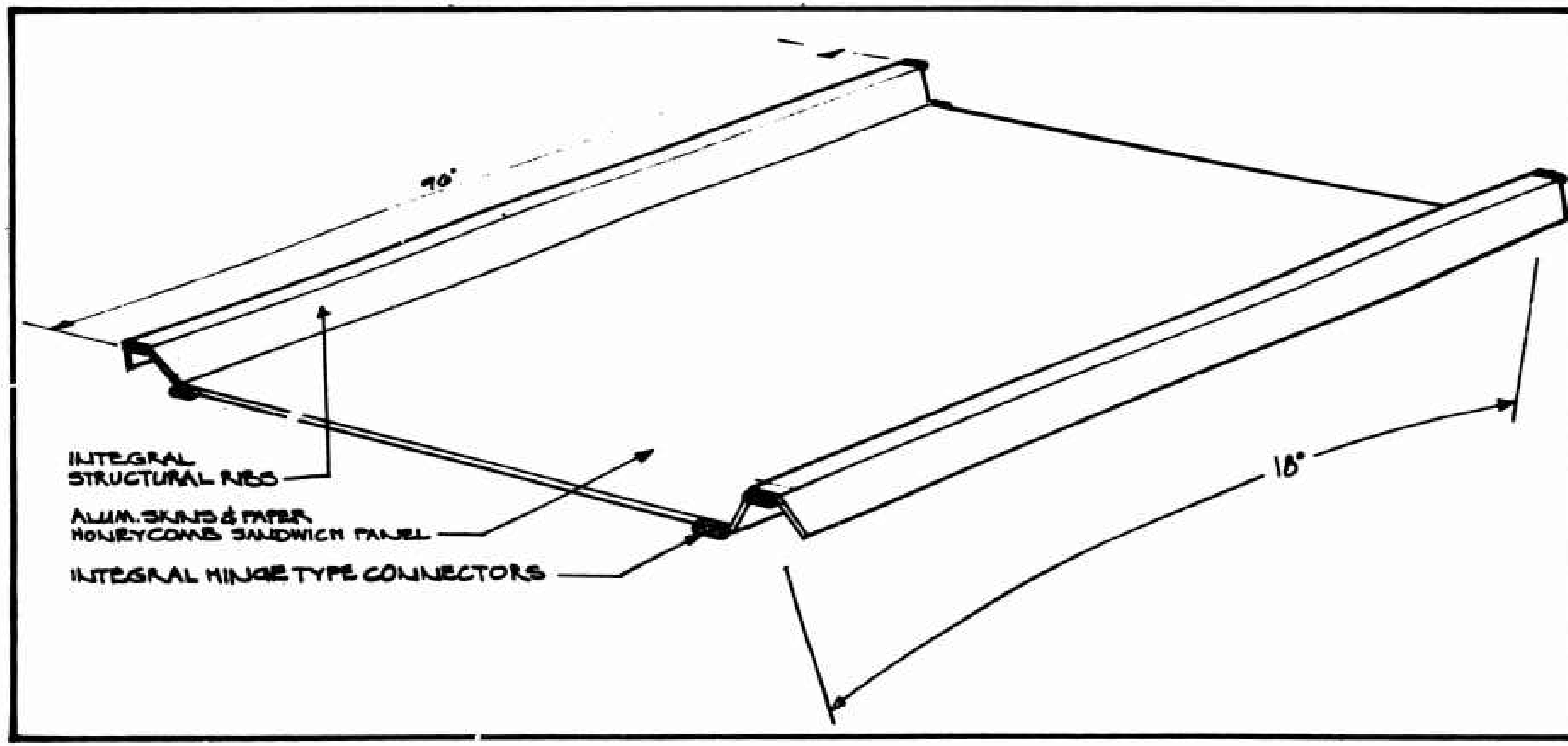


Figure 65. Panel and Rib Module

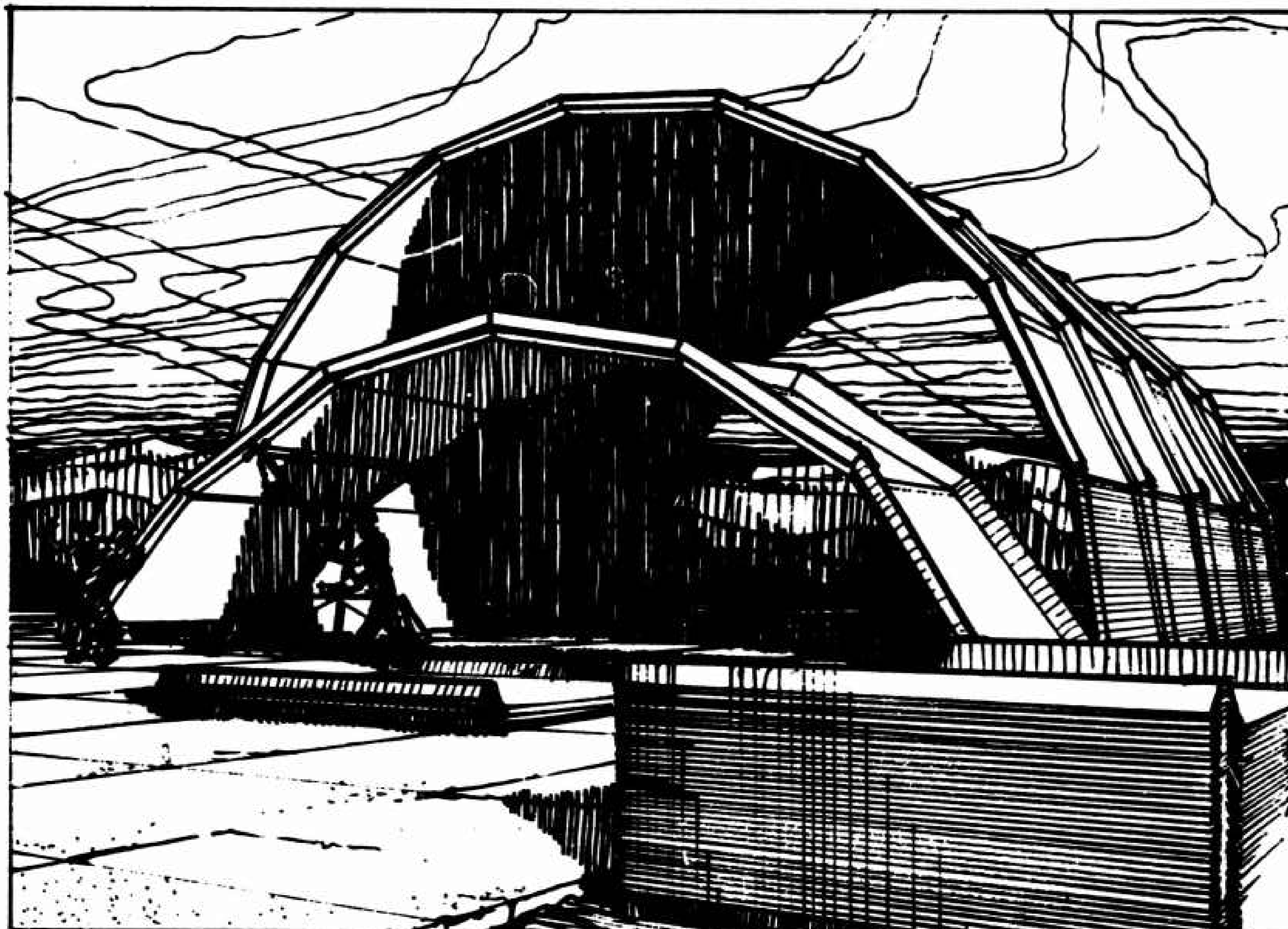


Figure 66. Panel and Rib Concept

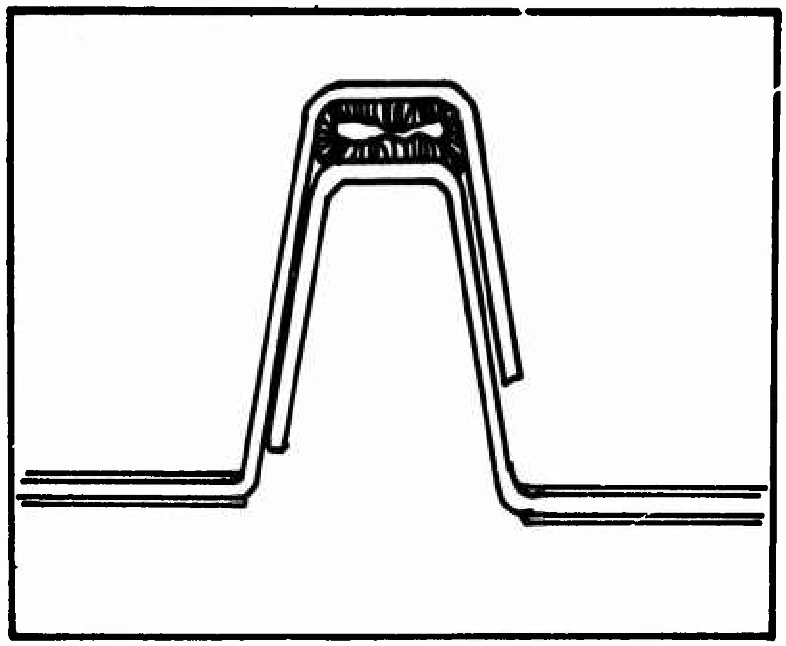


Figure 67. Vertical Joint

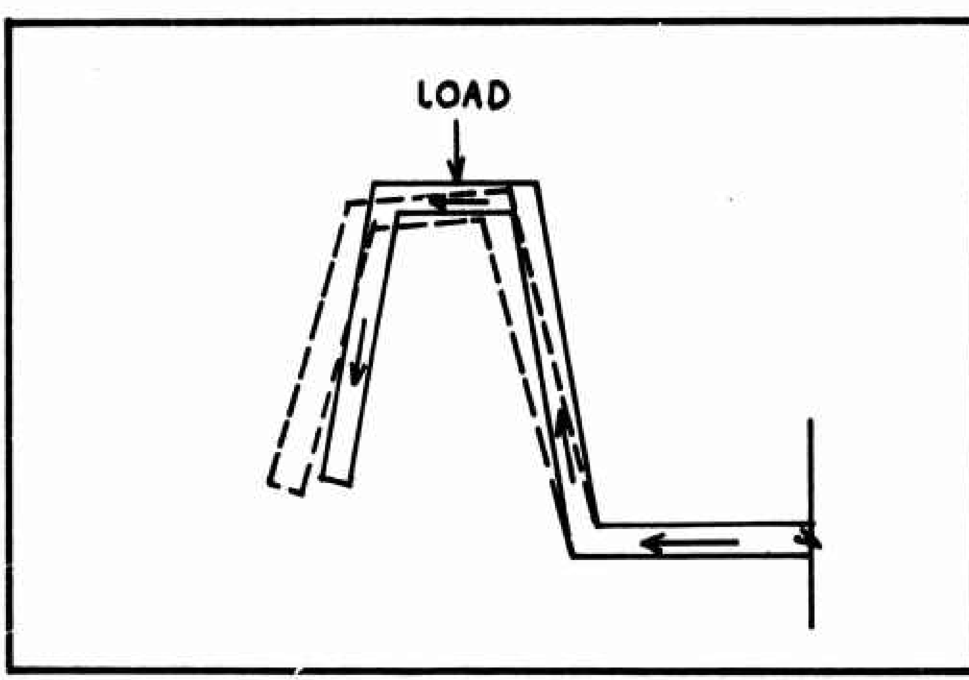


Figure 68. Arch Rib Deflection

D. BEAM, PURLIN AND SHEATHING CONCEPT

The panel concept discussed previously pointed out difficulties encountered with trying to design a single component to perform both structural and sheathing functions. Follow-on investigation indicated that considerable savings could be effected in packaged volume and fabrication cost by designing separate components to perform the various functions.

One such concept considered was generated by a study of a structure manufactured by Live Structures, Inc. in Stratford, Connecticut. This structure, as developed by Live Structures, consisted of 3-1/4" x 8" wood arch ribs spaced 8' apart with 1-1/2" aluminum tube purlins and 3/8" plywood sheathing. (Figure 69)

1. Erection

First, ten beam sections are assembled into an arch rib on the ground. Two such arch ribs are raised into a vertical position and tied in place by guy ropes. Then, starting at ground level, the aluminum purlins are attached to the arch ribs forming a ladder for use in carrying subsequent purlins up for attachment. When the purlins for one arch section are attached, the panels are pulled up over the arch and the arch to arch flashing is pulled over the arch beam and tied down. (Figures 69 and 70)

2. Erection Time

Erection time for this hangar concept was estimated by reviewing each step in the erection process. The erection of a hangar that is 100' long, including one rigid end wall and one fabric end wall, requires 102 man hours. For an 80' long hangar 94 man hours are required for erection. An 80' long hangar with two fabric end walls would require only 82 man hours for erection.

3. Package Volume

The package volume for this concept was estimated to be 1300 cubic feet for a 100' long hangar and 1125 cubic feet for an 80' long hangar. Note that as far as package volume is concerned, two hangars could be shipped on one C-130 aircraft.

4. Hangar Weight

Estimated weight of a 100' long hangar is 26,500 pounds and for an 80' long hangar is 22,600 pounds. These weights far exceed design goals and approach the maximum load for long distance C-130 flights. However for an 80' long hangar without the rigid end wall and packaging the weight could be reduced to 20,000 pounds. Follow-on investigations, reviewed in Section VI, achieved greater weight reductions by use of aluminum beams instead of wood beams.

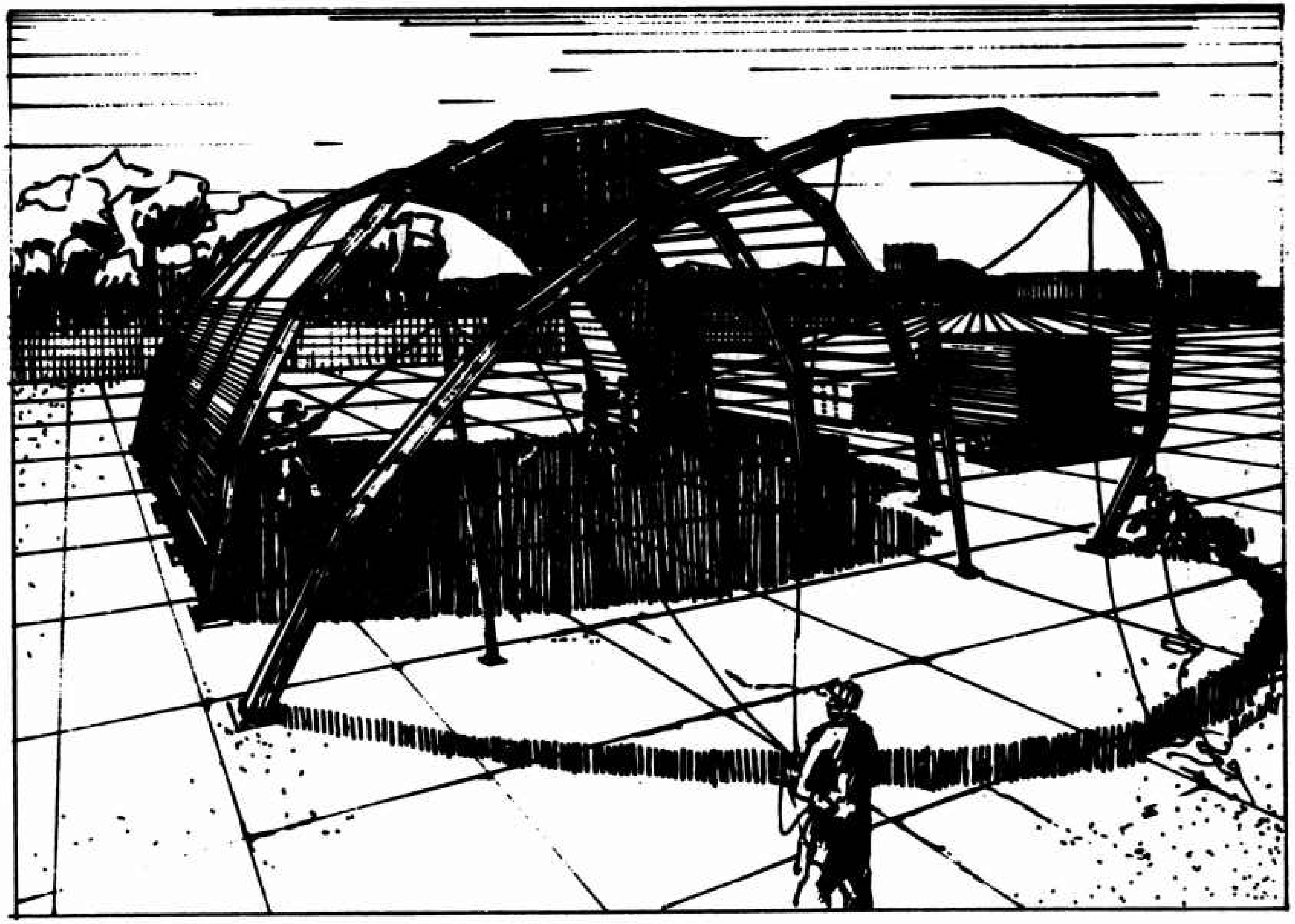


Figure 69. Beam, Purlin and Sheathing Concept

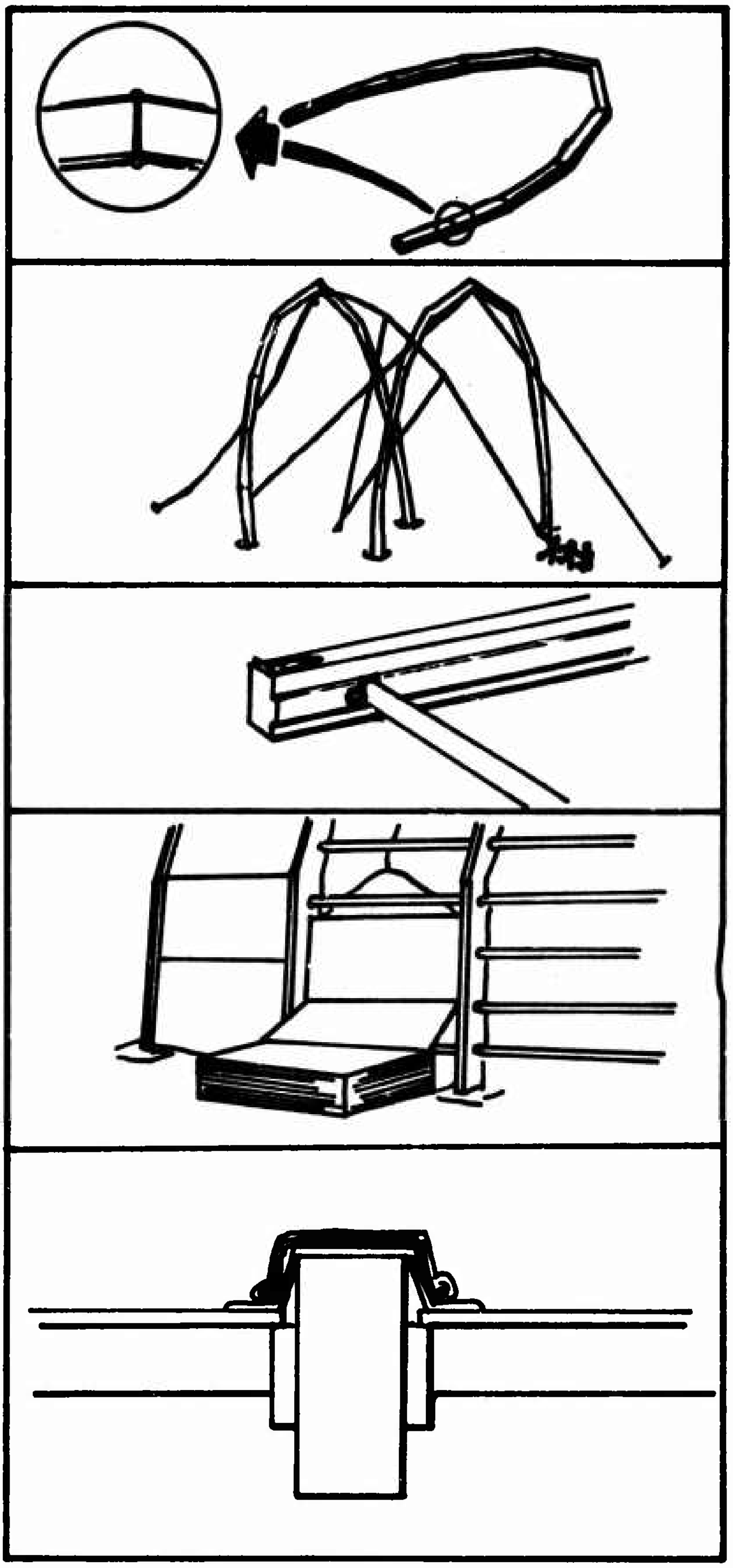


Figure 70. Erection Sequence

5. Beam Test

In an effort to reduce weight of the arch beam sections, a wood and aluminum composite beam was fabricated and test loaded. The beam to beam hinge joint was fabricated using 2" x 10" lumber, 1/4" aluminum plate top and bottom and steel hinges. (Figure 71) (This type of steel hinge is developed further in Section V). The hinges and aluminum plates were attached to the wood beams with lag screws. The joint failed at about half of the design loading due to buckling of the hinge under compression which pulled out the lag screws.

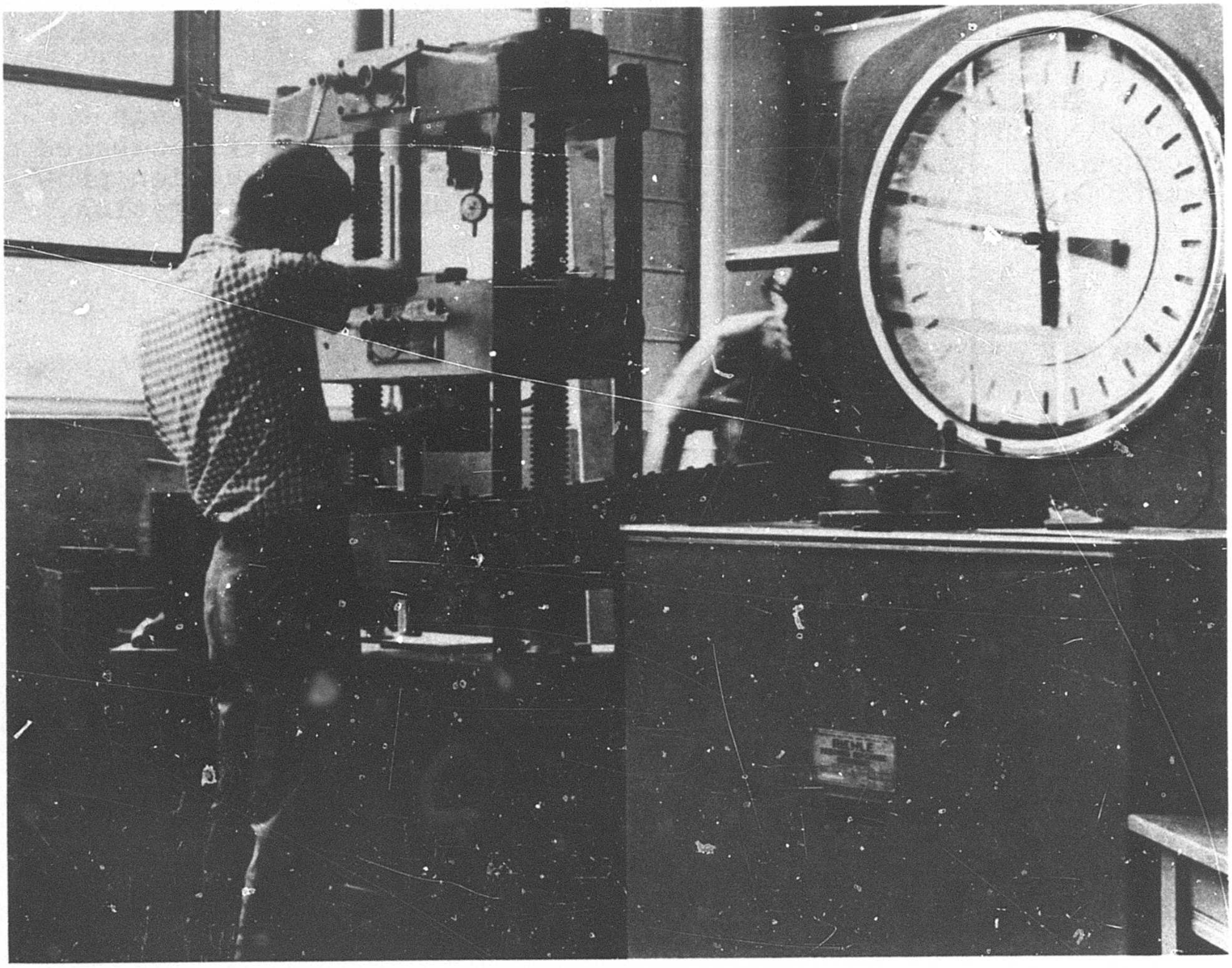


Figure 71. Composite Beam Test

6. Beam and Purlin Mock-Up

A brief study of the method of attachment of purlins to the center of wood beams was made. Figures 72 through 78 show two systems of purlin attachment. In both systems the purlins pass through the center or neutral axis of the arch ribs. This is an improvement over the "Live Structures" concept which attaches the purlins flush with the top of the arch ribs thus reducing the effective depth of the beam section. In one system the purlin ends are attached at the beams. In the other system the purlins pass through the beam ahd are attached to each other by means of a sliding sleeve with set screws. It was hoped that the second system would contribute to the stability of the structure by the continuity of the purlins. However, the slip tolerance required to slide the purlin through the beam reduced the effectiveness of this system. Therefore, the first system was proven to be the best because it required fewer steps for connection.

7. Supplementary Notes

This hangar concept exhibits improvements in package volume and manufacturing complexity over previously discussed concepts. However, problems anticipated in the erection process and structural stability require further investigation.

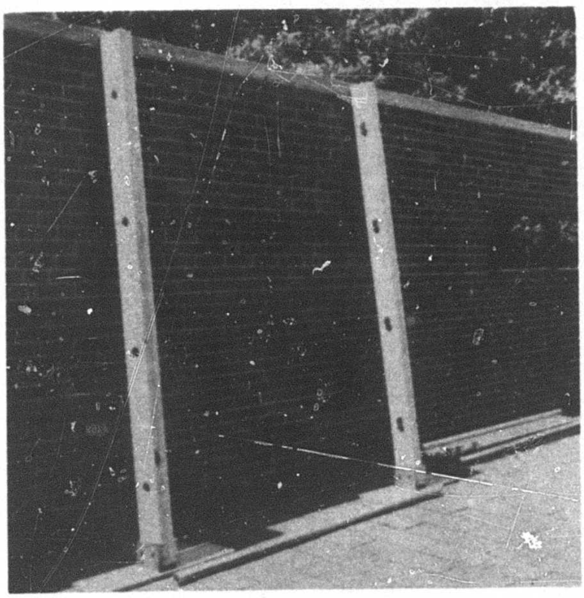


Figure 72
Beams with Center Holes

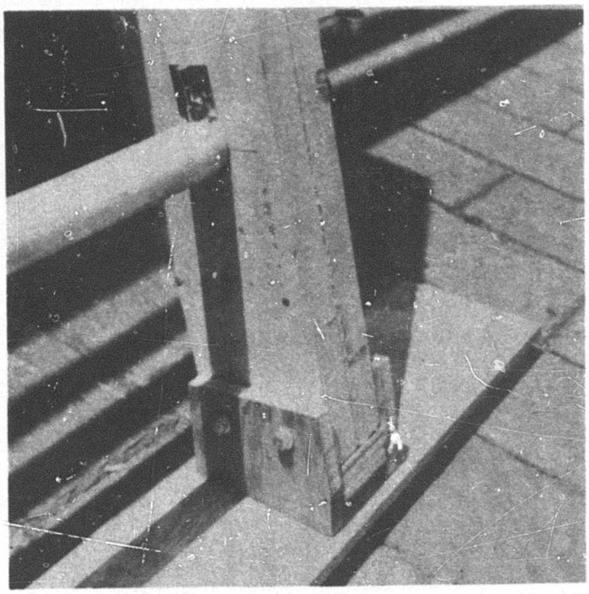


Figure 73
Purlin Attached to Beam

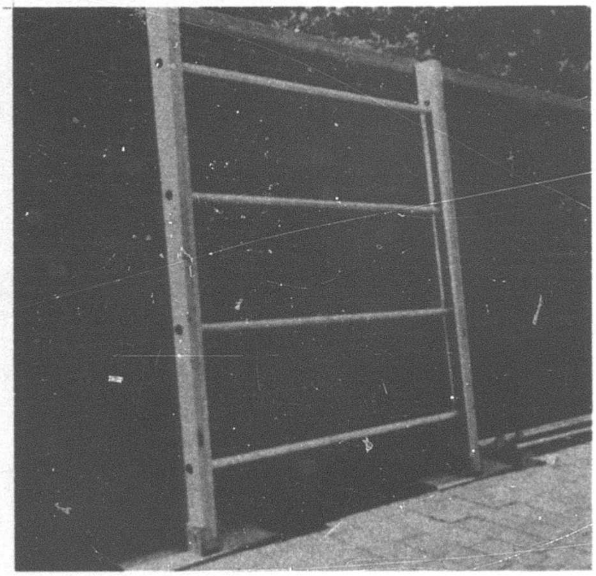


Figure 74
Purlins Spanning Beam to Beam

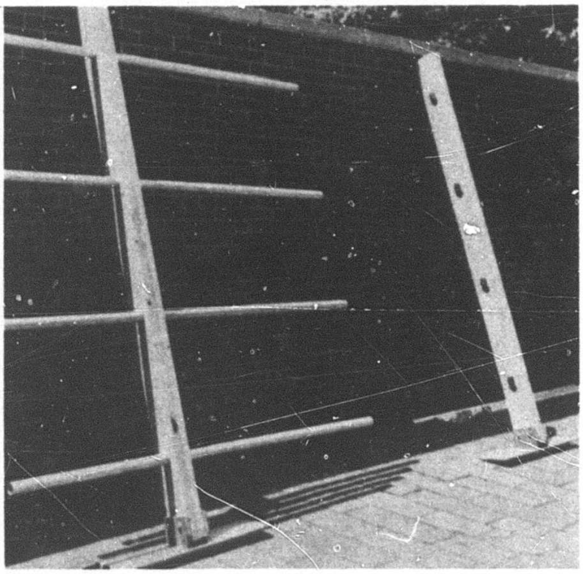


Figure 75
Purlins Pass Through Beams

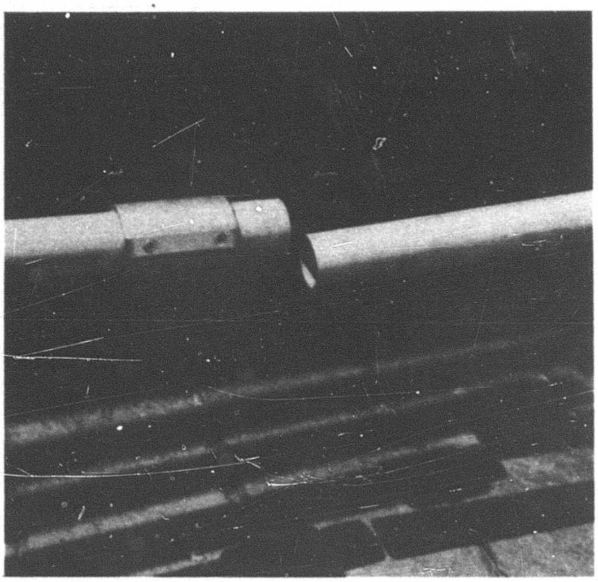


Figure 76
Center Sleeve

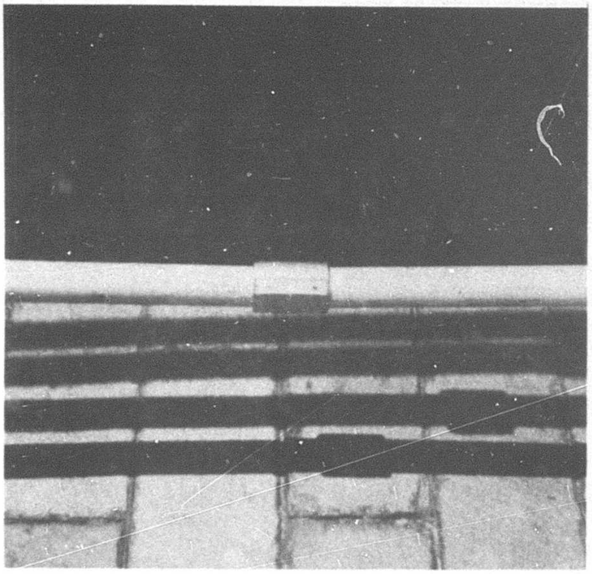


Figure 77
Center Sleeve Attached

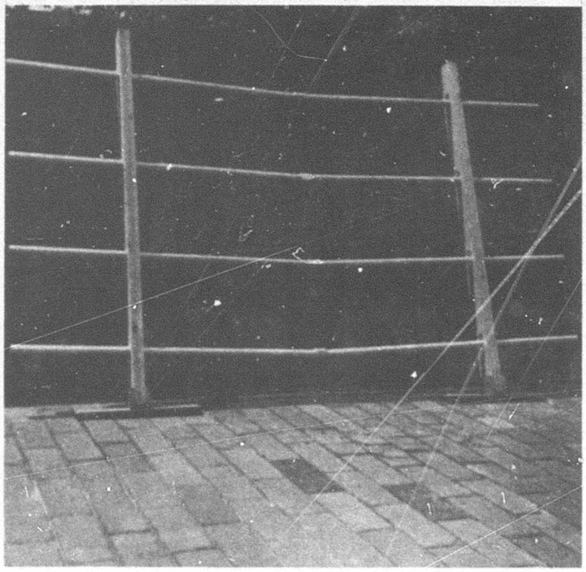


Figure 78
Purlins Continuous at Beams

E. PANEL AND BEAM CONCEPT

This concept was generated by a continuing investigation of the beam, purlin and sheathing concept. Since the purlins did not provide the required structural stability to the hangar arch ribs, the sheathing panels must be relied upon to do the job. With this additional requirement of the sheathing panels, it is proposed in this concept that a structural panel be used in lieu of both purlins and sheathing panel. Also mock-up studies of erection techniques generated a structure with double arch ribs.

1. Third Scale Mock-Ups

A one third scale mock-up was fabricated for testing various erection methods. The arch ribs were made from 2" x 4" lumber and the joints were connected by inserting pins into strap hinges which were located on the top and bottom of each joint. Each erection method was tested with wood purlins and then with panels made from 1/4" Technifoam which had a polyurethane foam core and paper skins. In all three cases the arches with the panels were much more rigid and easier to work with during erection.

The first erection method tried consisted of assembling the whole arch on the ground and pulling it up with the use of poles and cables. (Figure 79) The force needed to lift the arch in this manner would require a large hand winch well anchored in the ground. The two poles needed for pulling up the arch would have to be 25' long which would make working with them awkward.

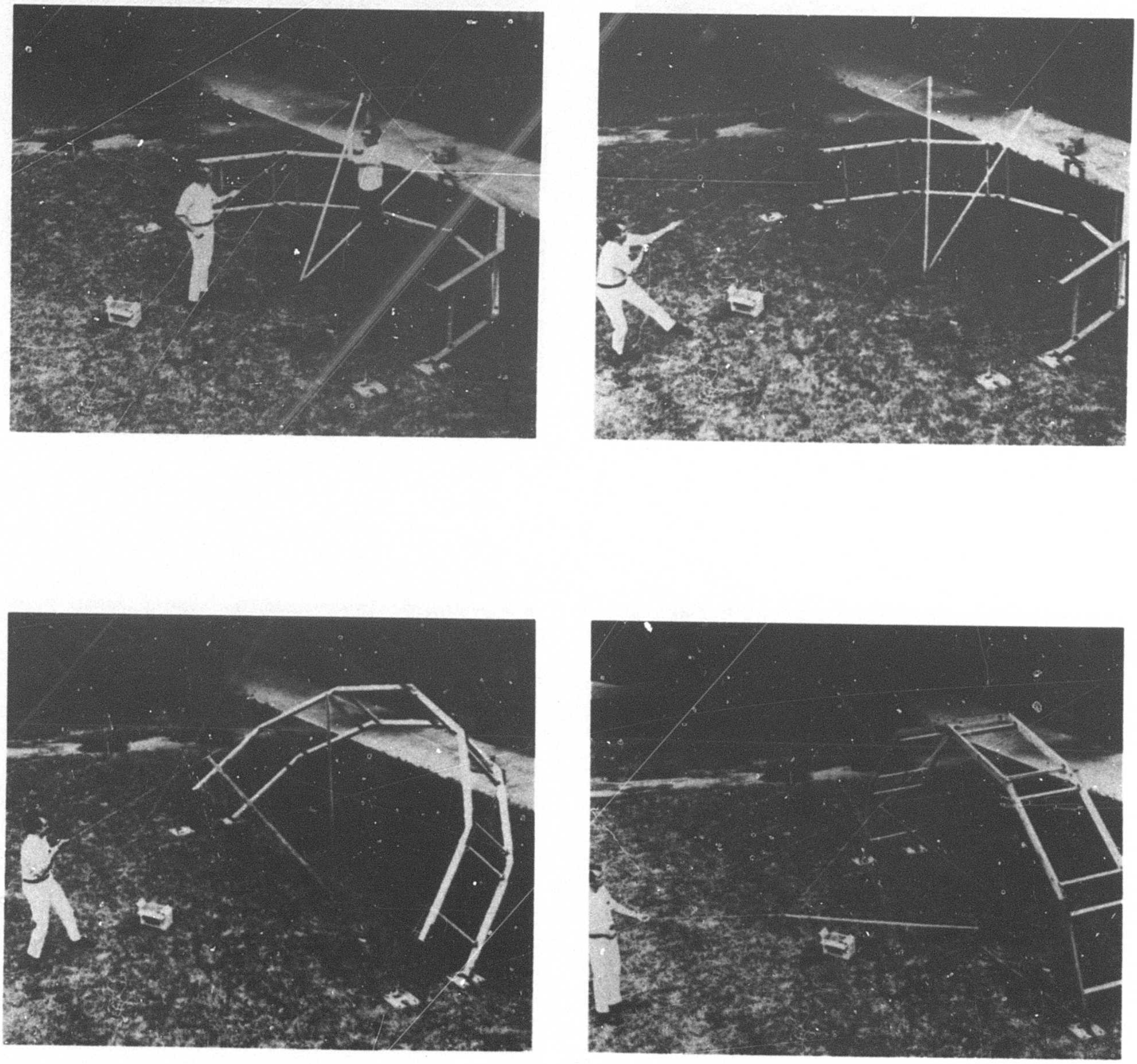


Figure 79. Whole Arch Tip-up Sequence

The second erection method tested consisted of assembling one half of an arch on each side of the hangar and raising each half independently until they met in the middle or apex of the arch. (Figure 80) The arch was most difficult to raise by this method and the apex connection 25' in the air would be difficult to make.

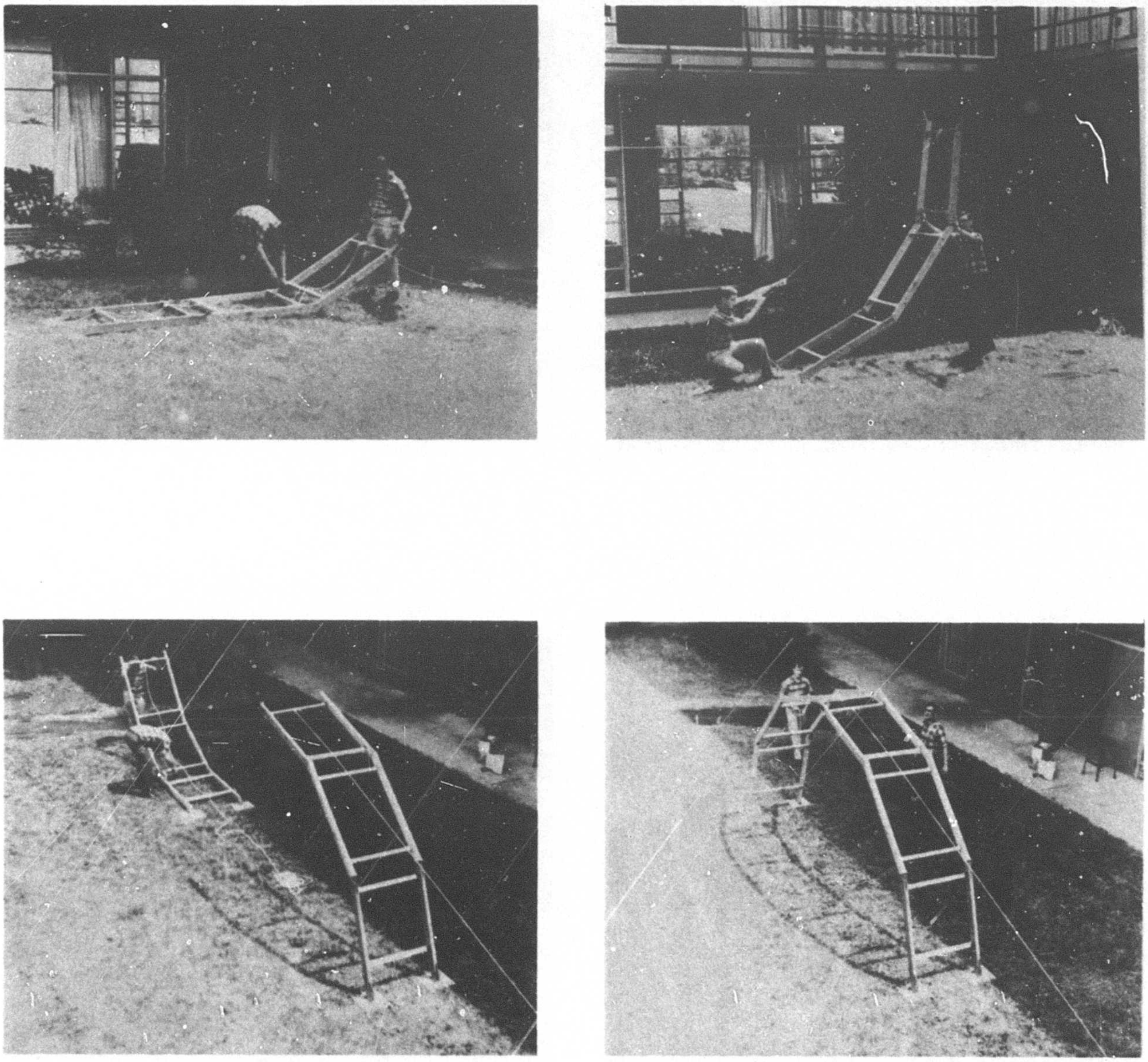


Figure 80. Half Arch Tip-Up Sequence

The third erection method tested consisted of raising the arch progressively as each panel module was attached. (Figure 81) The arch remained most stable during this erection sequence due to the fact that it acted as an arch throughout the erection. This method required least effort and tolerances required for erection were least critical.

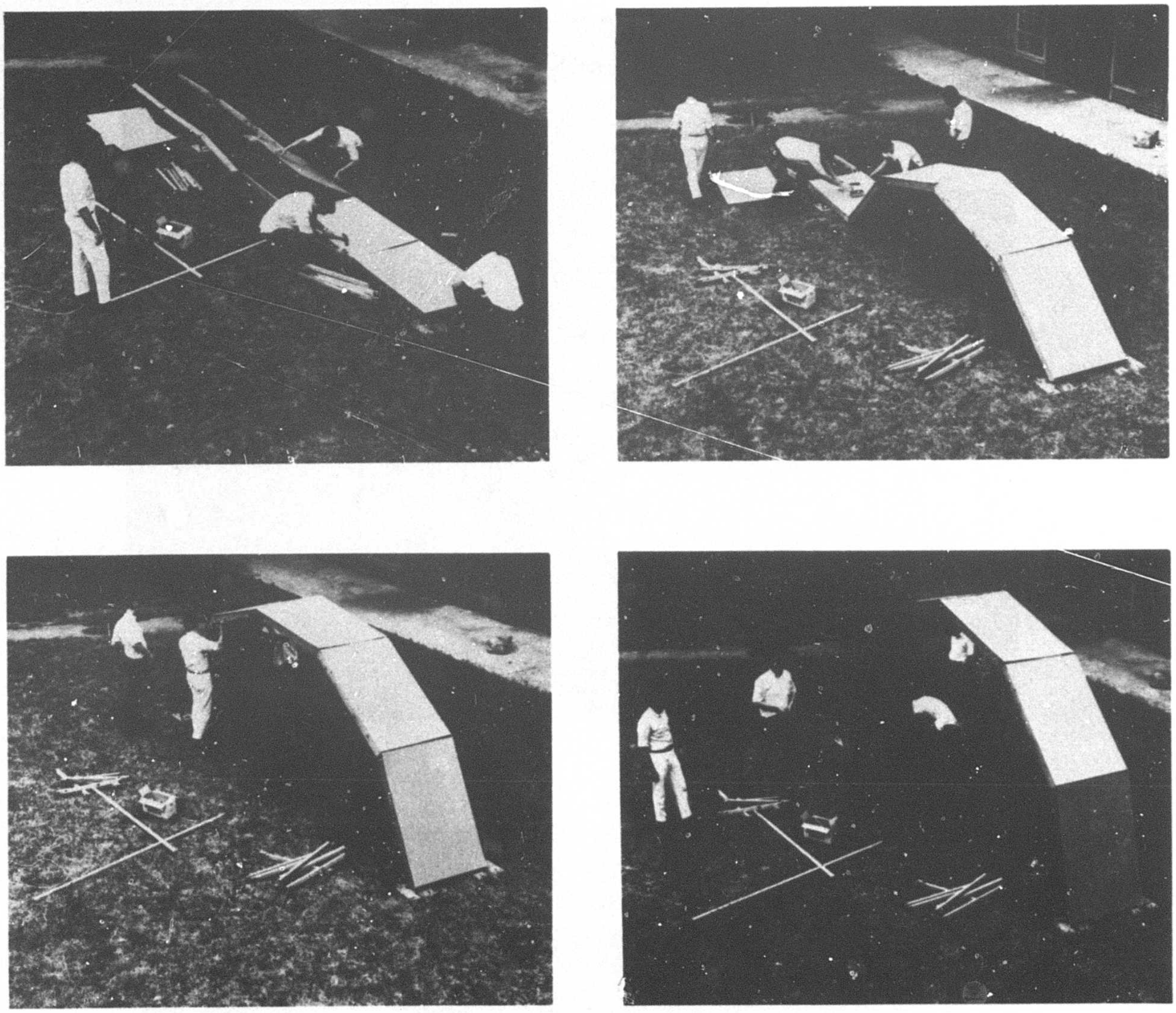


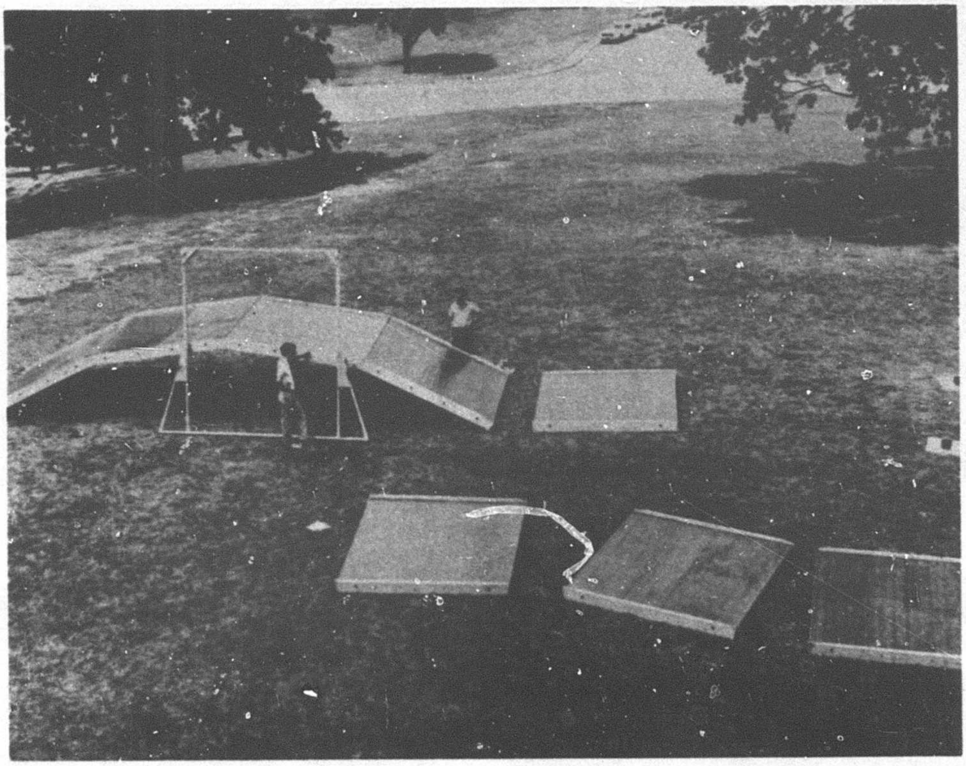
Figure 81. Progressive Arch Raising Sequence

2. <u>Full Size Mock-Up</u>

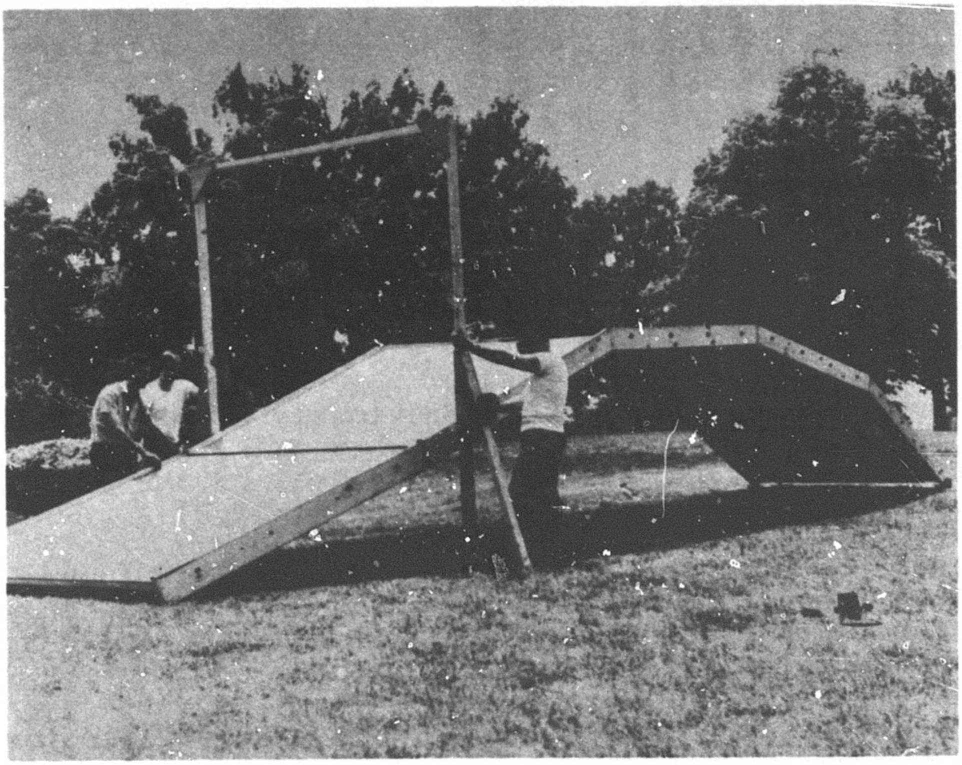
The third erection method previously mentioned was further investigated. A full size arch mock-up was fabricated for testing to get a more realistic appraisal of the problems involved during erection. (Figure 82 A,B,C,D)

The arch ribs were fabricated from 2" x 8" lumber and connected at the joints by inserting pins into strap hinges top and bottom. Panels were 1/4" Technifoam, with epoxy impregnated paper skins, nailed to an 8' x 8' wood frame.

The winch erection device had several deficiencies. First, the spacer bar on the ground had to be dismantled after completing each arch in order to move it on to the next arch to be

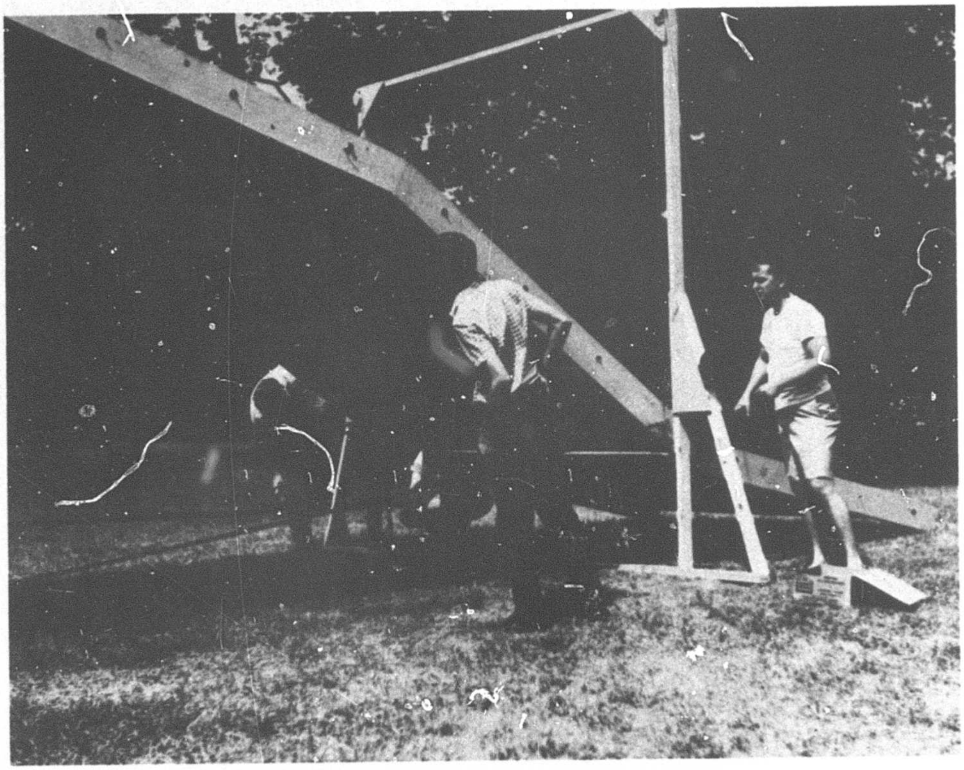


A

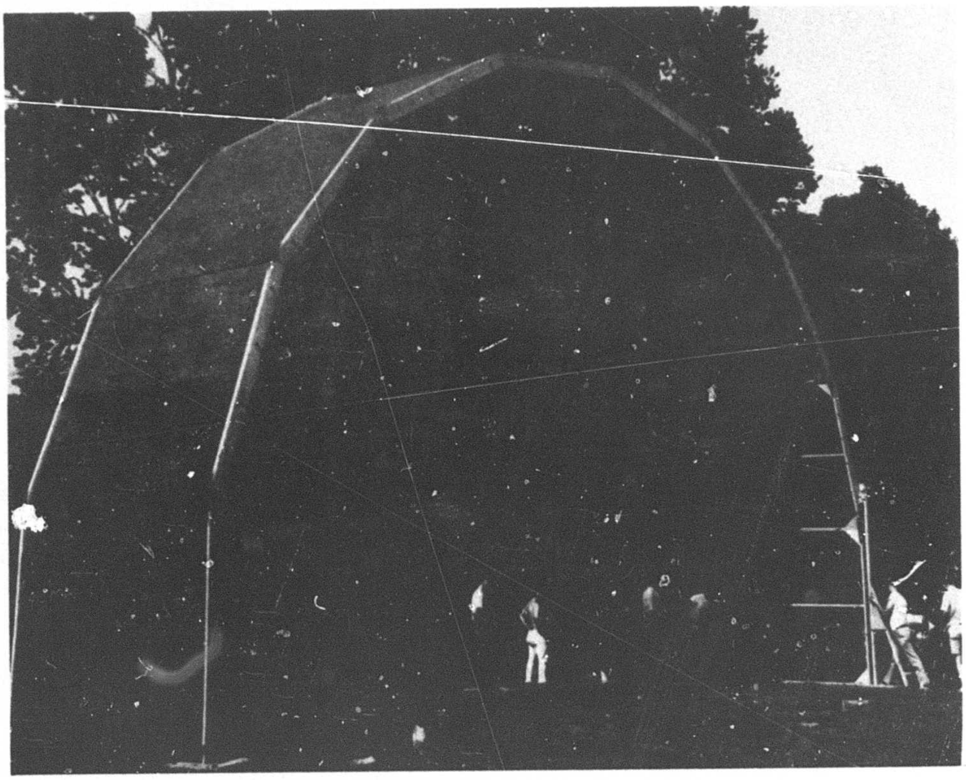


B

Figure 82. Full Size Mock-Up Erection



C



D

Figure 82. Full Size Mock-Up Erection

erected. It was found that, due to friction between the side posts and the ground, the ground bar was not required. The height and width needed to be increased to allow more clearance for the arch. Also, the winch device was unstable when the end of the arch being raised was close to the ground.

A second winch device, or gantry, was mocked-up out of lumber. It omitted the spacer bar on the ground, increased the size, and braced against rocking. (Figure 83) For the final hangar system this gantry will be fabricated from aluminum sections for greater strength and durability. The side "A" frames and top horizontal bar would be demountable in order to fit into the hangar package and be compatible with the 463L pallet system.

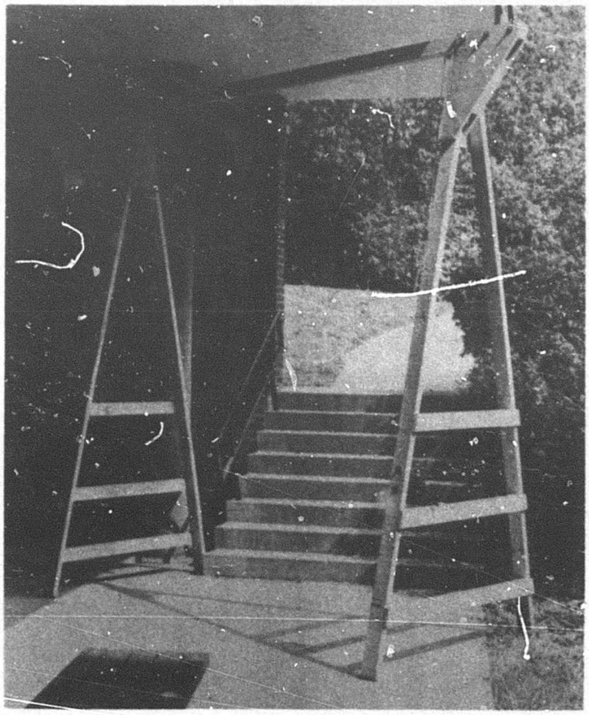


Figure 83. Revised Erection Gantry

This erection method required that the hangar arches have a space between them to allow room for the erection gantry. These arches are then connected together with variable length spacers. These spacers allow for variations in terrain and remove the need for elaborate leveling devices on the foundation pads. They also function as a ladder by which any arch panel can be removed for repairs and counter flashing can be installed over the spacer gap between arches.

To briefly recap, the erection procedure would be:

a. Assemble arch modules by attaching beams to each side of the panels. (Figure 84)

b. Erect an arch by assembling 10 arch modules in sequence using the erection gantry. (Figure 85)

c. When two arches are erected, connect arch to arch by locking spacers. (Figure 86)

d. Pull counter flashing over the arch and tie down at base pads to seal gap between arches. (Figure 87)

The beam and panel concept configuration and erection method are shown in Figure 88.

3. Evaluation of Concepts

Estimated package volumes, erection times, weights and costs for the concepts discussed in this section are compared with these statistics for the Double Curvature Concept in the Following chart:

CONCEPT	VOLUME CU. FT.	ERECTION TIME MAN HOURS	WEIGHT POUNDS	COST DOLLARS
Double Curvature	1350	150	18,400	144,000
Single Curvature	2120	150	19,000	90,000
Double Bend	1350	150	18,000	110,000
Integral Beam	900	80	17,500	80,000
Beam, Purlin and	1125			
Sheathing	1125	82	22,600	40,000
Panel and Beam	1175	85	18,000	45,000

The single curvature and double bend concepts made improvements over the double curvature concept only in the area of costs. Their erection times and costs remain far too high. Problems inherent with these concepts are:

a. The arch to arch connectors are complex, expensive and do not provide much tolerance for locking. This problem of misalignment would be amplified during the erection process under windy conditions.

b. Close tolerances required in these arch connectors would require elaborate leveling devices on the base pads.

c. If a panel module in the middle of a hangar is damaged, half the structure would have to be dismantled to replace it.

The panel with the Integral Beam Concept provided significant improvements in package volume and erection time due to the efficient stacking of panel modules and the improved erection techniques. However, it was proven to be an impractical concept due to the problem of the structural rib deformation.

The beam, purlin and sheathing, and the beam and panel concepts exhibited the most promise from the standpoints of volume, erection time and cost. If one of these concepts could be reduced in weight to 14,000 pounds, it would be possible to ship two hangars on one C-130 aircraft.

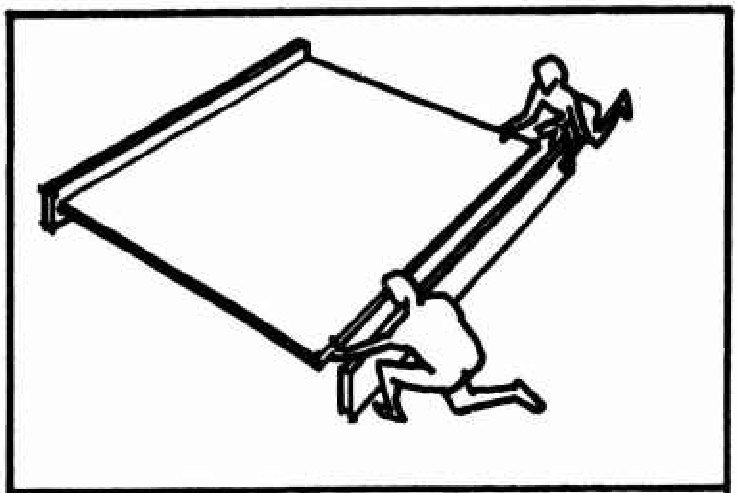


Figure 84
Assembly of Arch Modules

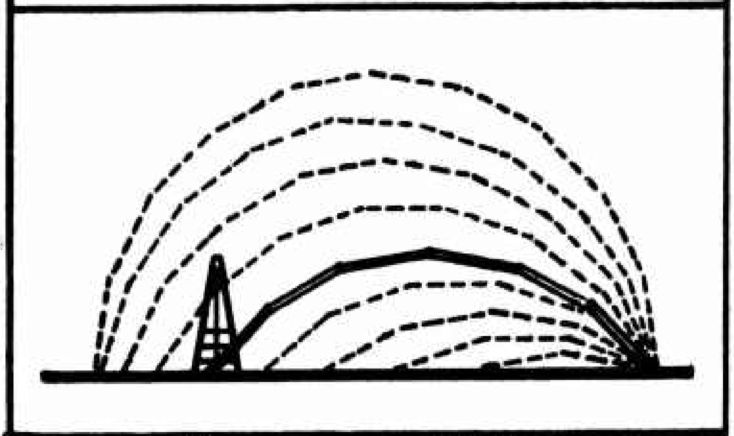


Figure 85
Progressive Arch Erection

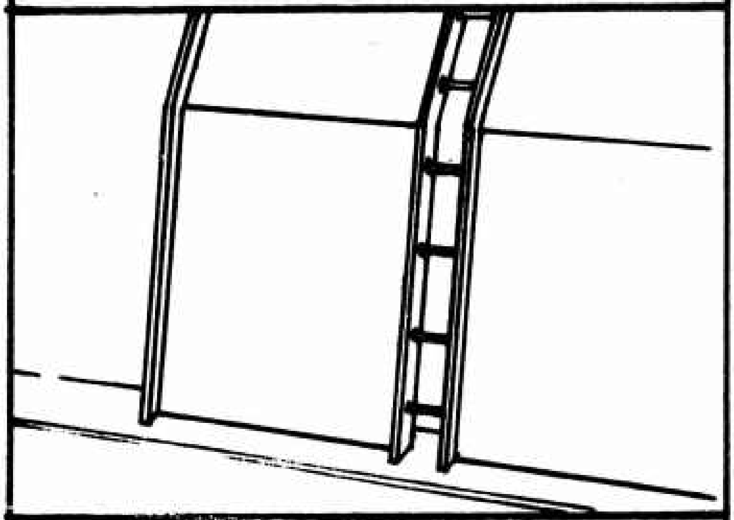


Figure 86
Arch Spacer Connection

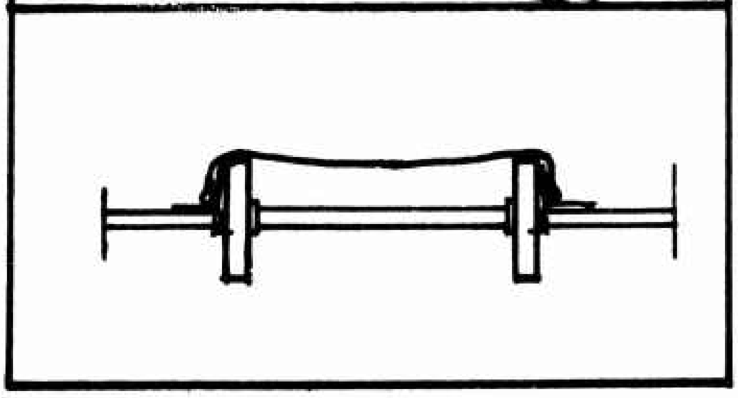


Figure 87
Pullover Fabric Center
Flashing Section

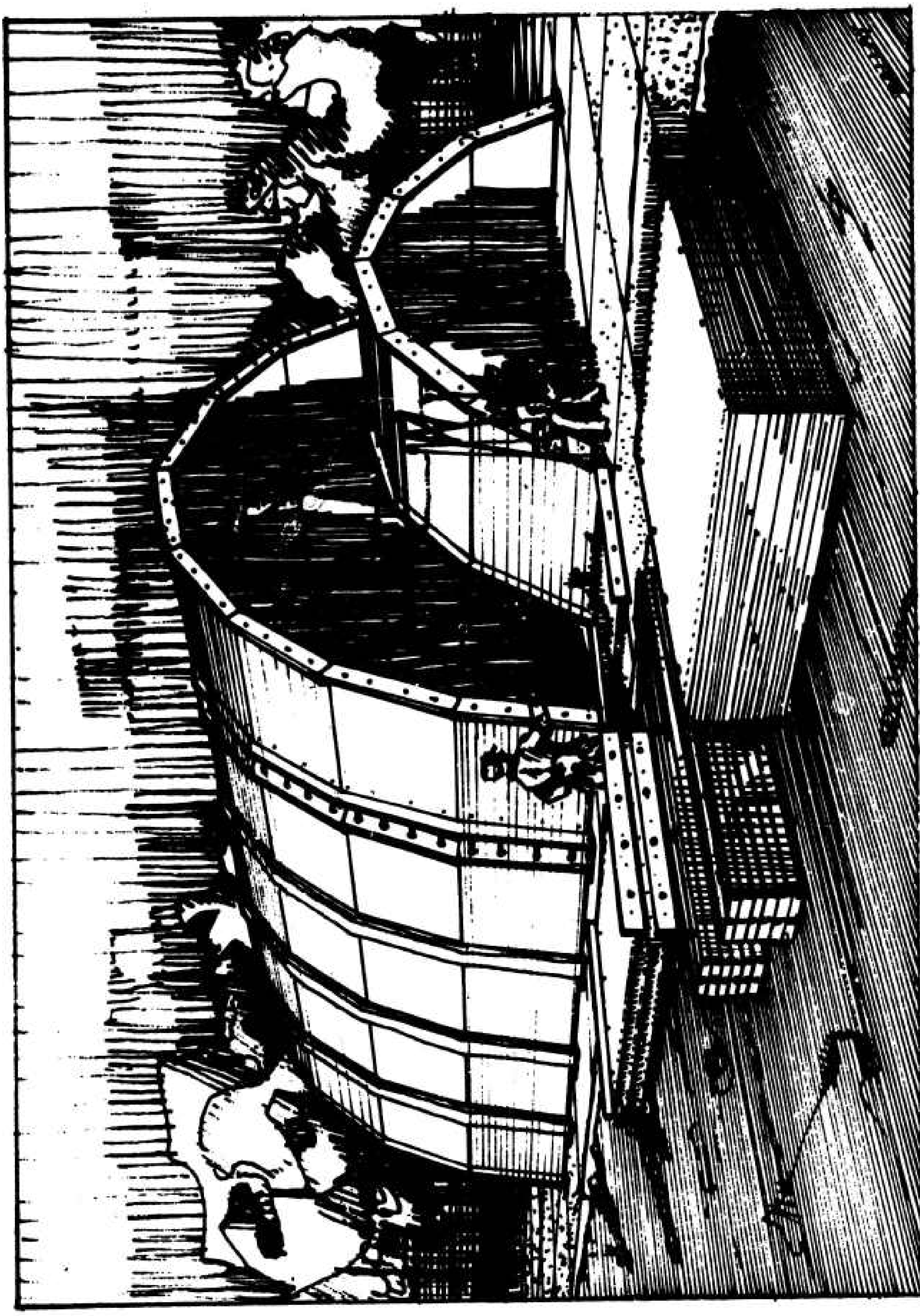


Figure 88. Beam and Panel Concept

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V

CONFIGURATION VARIATIONS:

HANGAR AND GENERAL PURPOSE SHELTER

One characteristic of the segmental arch (beam and panel concept) is the capability of achieving variations in shelter configuration. These variations can be achieved by changing the number of panel-beam modules and by changing the angle at their points of attachment.

A. <u>POSSIBLE VARIATIONS</u>

This study of configuration variations generated an improved hangar configuration and demonstrated the feasibility of adapting standard hangar components to a smaller general purpose shelter.

1. First, three variations that were based upon components of the 50' span by 25' height by 80' long hangar were investigated. (Figure 89) The small configuration could be adapted to use as a personnel shelter. The intermediate size configuration could be used as a general purpose shelter, and the larger configuration could be used as a warehouse or general assembly shelter.

An analysis of these structures indicated that the medium or general purpose size was practical structurally. The change of angle from the side wall arch beam to the roof arch beam tends to increase the stresses at these points. Since the medium size shelter is appreciably smaller than the hangar, the stresses at these "knee" joints are within the allowable limits of the standard joint design. The smaller configuration provides a much heavier structure than is required for such a small building.

2. The 25' high hangar configuration is 8' higher than the tail of the F-4 aircraft for which it is designed. It was observed that if only nine panel-beam modules are assembled into an arch, 4' of clearance can be provided. (Figure 90) Since this is adequate clearance, a study was made of variations of this configuration. (Figure 91) Two problems are presented in this new hangar configuration. First, the horizontal position of the top panel-beam module causes water drainage problems. This could be offset by sloping the panels down from the center of each beam. Second, the new configuration does not provide the required 5' wing tip clearance. Therefore, the arch span would have to be increased to provide this needed clearance.

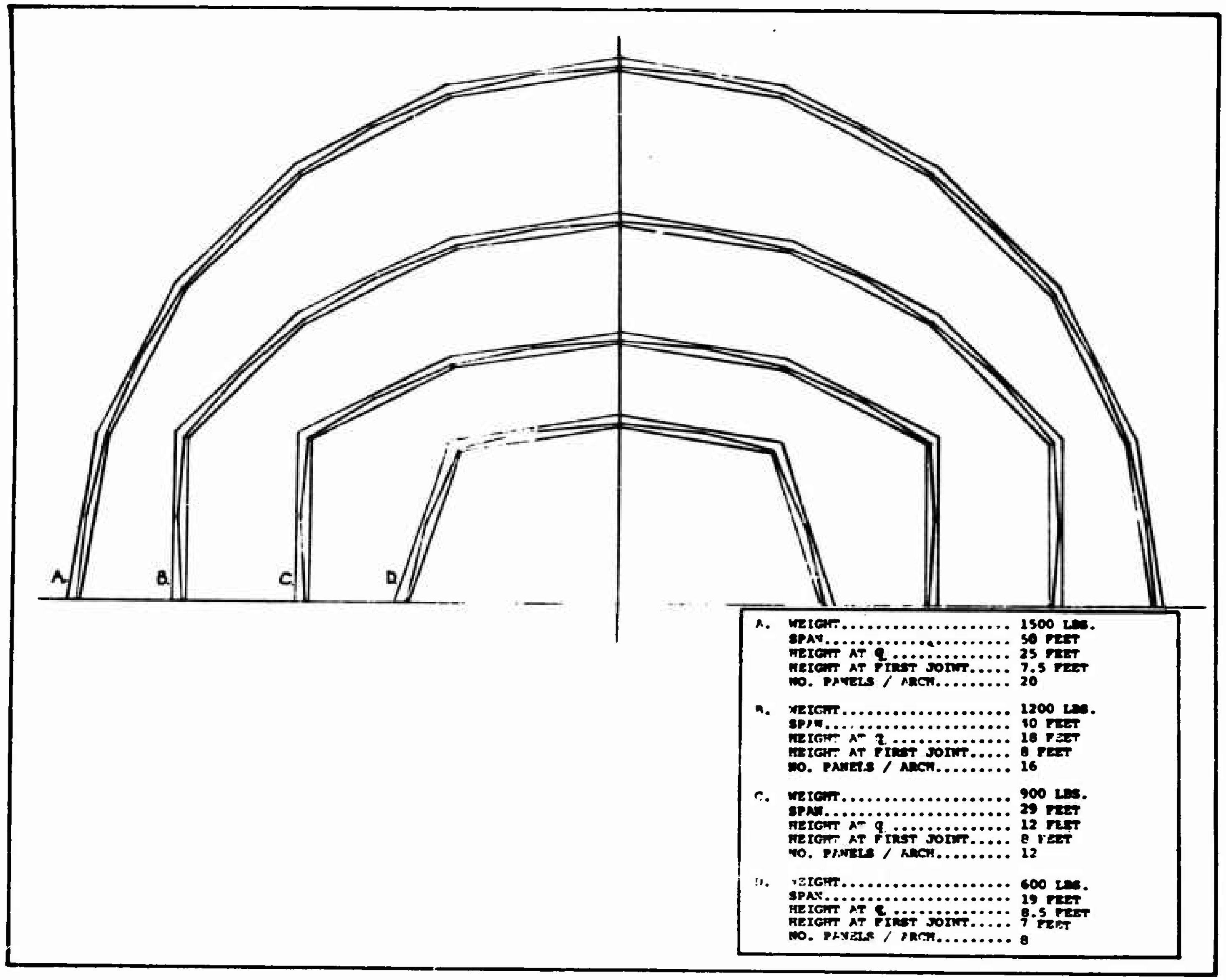

Figure 89. Configuration Variations Based on 50' x 25' Hangar

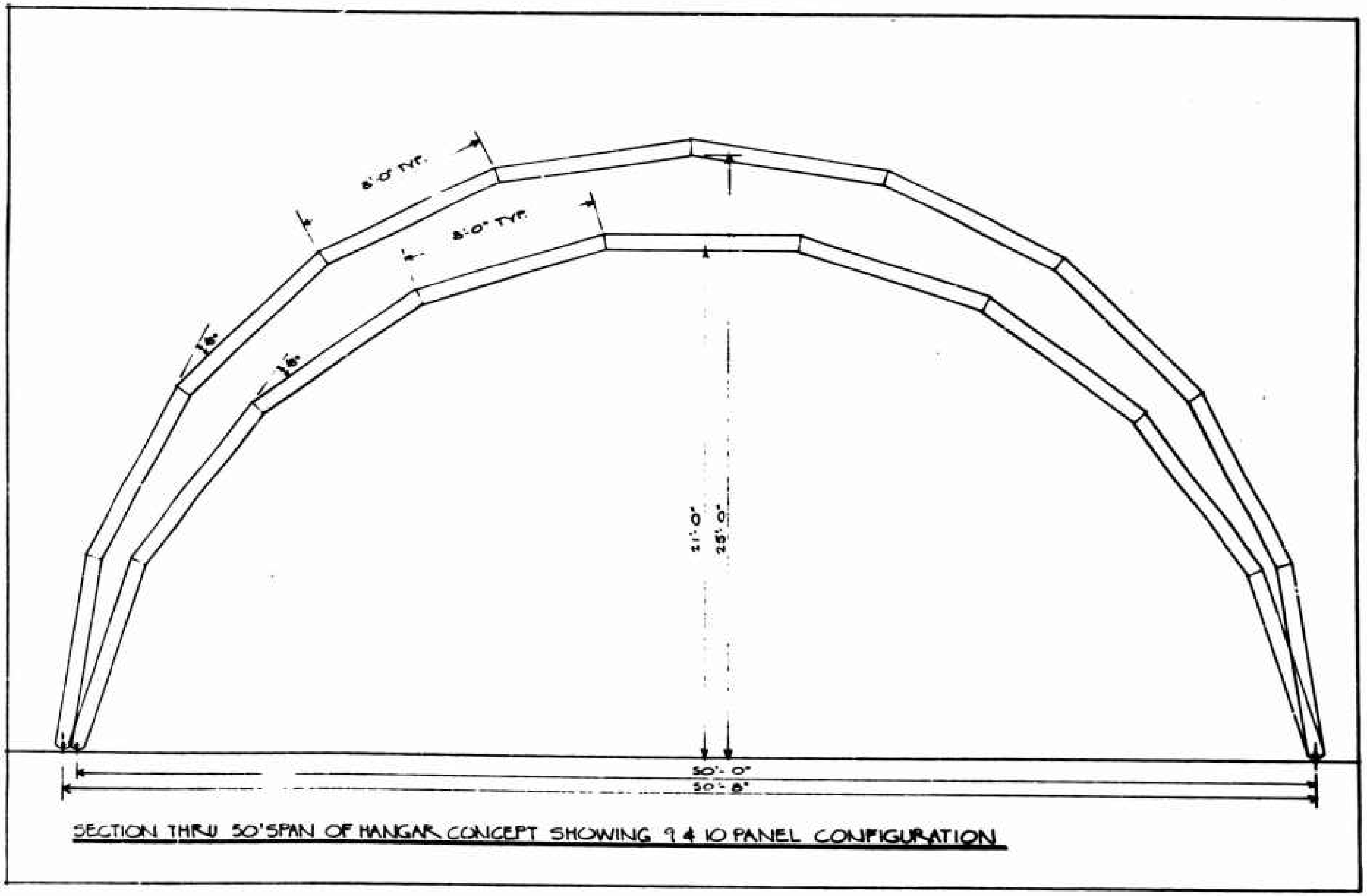

Figure 90. Configurations with 9 and 10 Panels

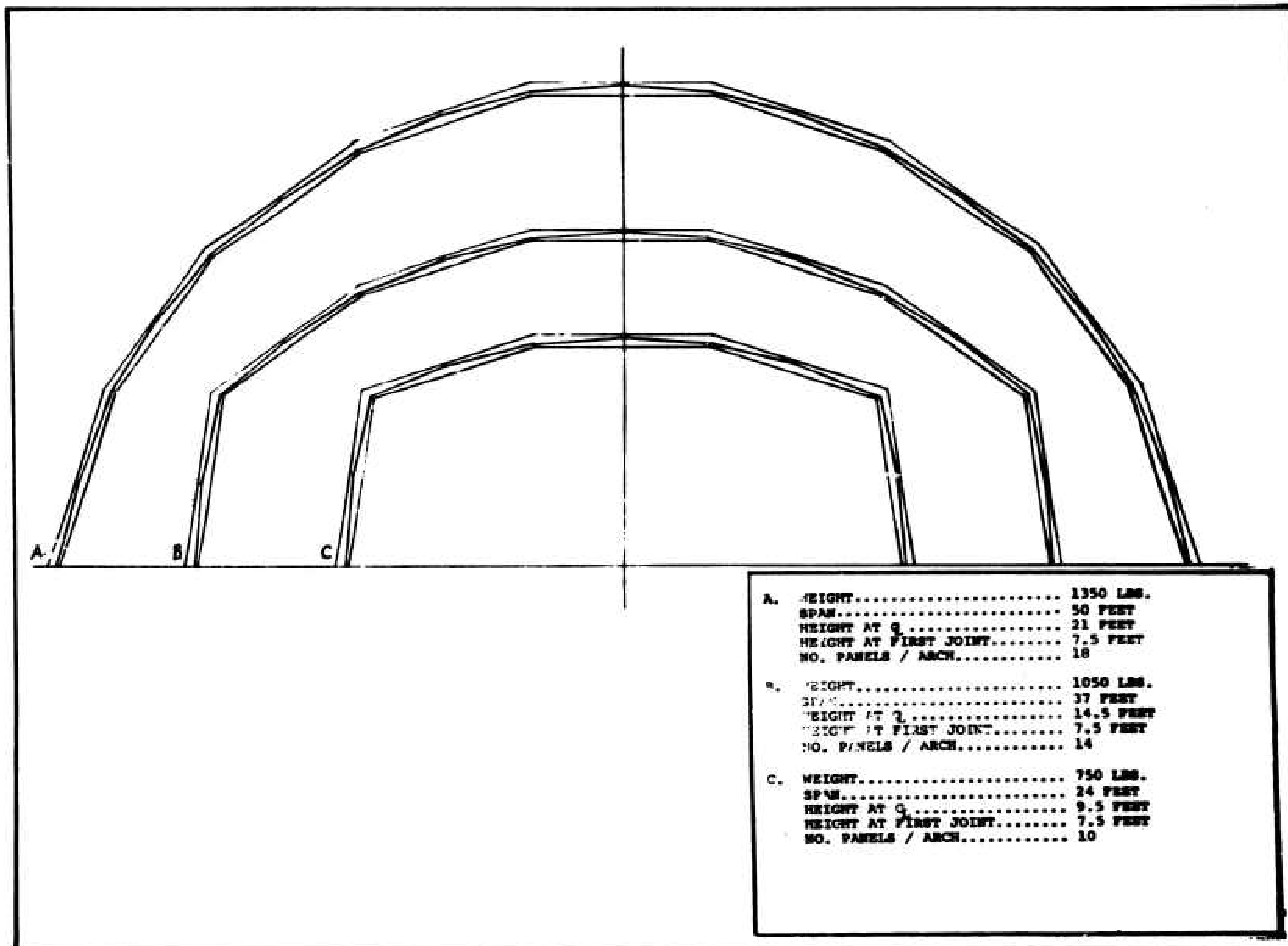

Figure 91. Configuration Variations Based on 50' x 21' Hangar

B. NEW HANGAR CONFIGURATION

The lower height hangar configuration was investigated to provide the required 5' wing tip clearance.

1. The nine beam-panel module hangar configuration has a 58'-2" arch span. (Figure 92, left side) The panels would have to be sloped down from the center of each arch beam in order to provide water drainage on the top horizontal beam-panel module. This made water proofing the counter flashing more difficult because of the variations of dimension from panel surface to top of beam.

2. By reducing the arch beam length from 8'-5" to 7'-7" a ten beam-panel module hangar configuration is achieved (Figure 92, right side). In this scheme the panels can be parallel to the beams and provide the required watershed.

Advantages of the 20' high x 58' span hangar configuration over the 25' high x 50' span hangar are:

a. A 5% reduction in shelter weight

b. Reduced stresses in beams due to lower height

c. Reduction in enclosed volume by getting rid of unused height

d. Increased usable floor area

C. GENERAL PURPOSE SHELTER

As pointed out in paragraph A of this section, intermediate size shelters assembled from standard hangar components are structurally practical.

At a meeting at Headquarters TAC, 8 August 1967, the basic decision was made to design the general Purpose Shelter, utilizing the same components as used in the Panel and Beam Hangar. The design of the General Purpose Shelter was a task under Contract F33615-67-C-1259, and preliminary work is covered under the final report of that contract.

Because of the commonality of basic elements between the two shelters resulting from this design decision, reporting of, detailed design, fabrication and testing of the General Purpose Shelter from this point on is covered in this report and will parallel discussion of the same phases of the hangar program.

Methods for achieving the General Purpose Shelter configuration using standard hangar components were investigated.

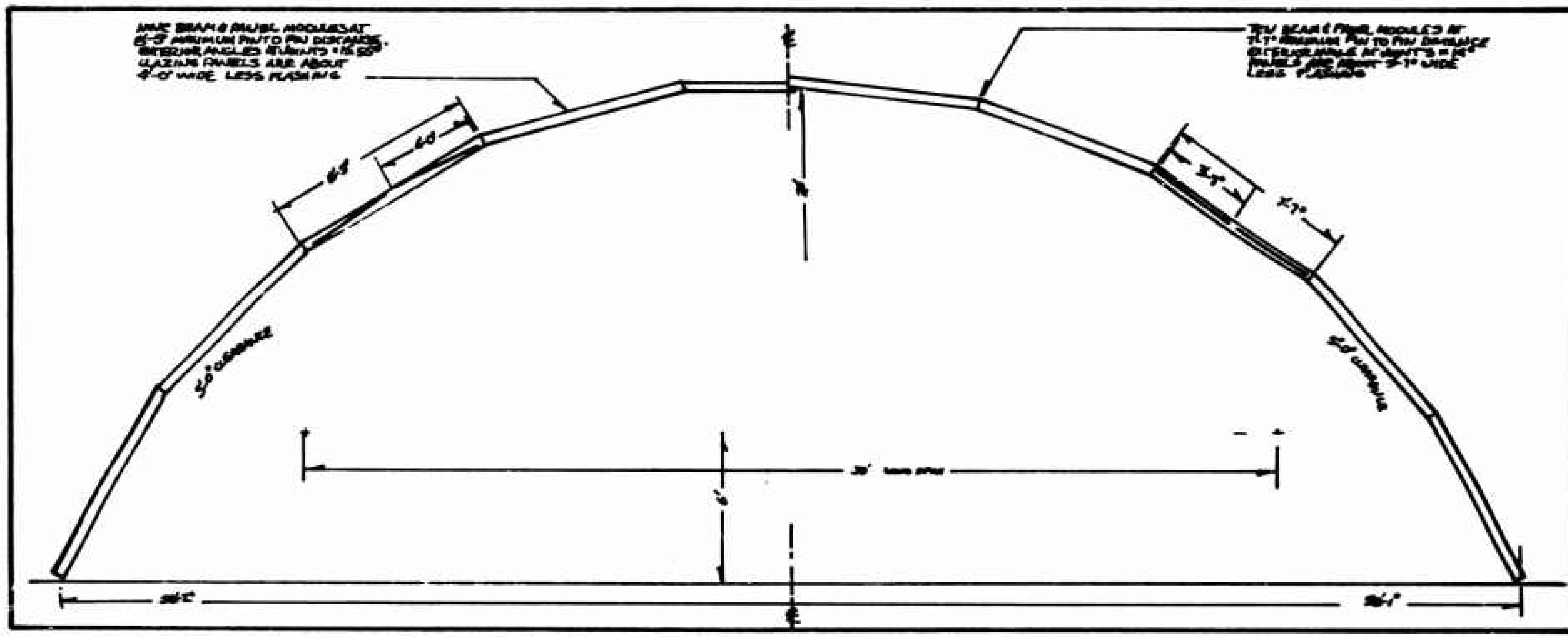

Figure 92. 9 and 10 Panel Configurations with Increased Span

1. <u>Ground Conditions</u>

The condition where the beams and panels meet the ground is essentially the same on both the hangar and the General Purpose Shelter. (Figure 93)

The base arch beams pivot on a pinned attachment to the base pad. This allows a simple ground skirt close-out between panel and ground to weather seal the side wall at any angle.

2. <u>Knee Joint</u>

Two methods of making the transition between the side wall and roof were investigated.

a. The side wall arch beam could be fabricated to have the special angle required to attach to the roof arch beam. (Figure 94)

Also the distance between the side wall panel and the first roof panel increased because of this greater angle. This could be flashed out by increasing the length of the roof panel down-hill flashing. In this system both the base arch beams and the first roof panels would be special in that they could be used only on the General Purpose Shelters.

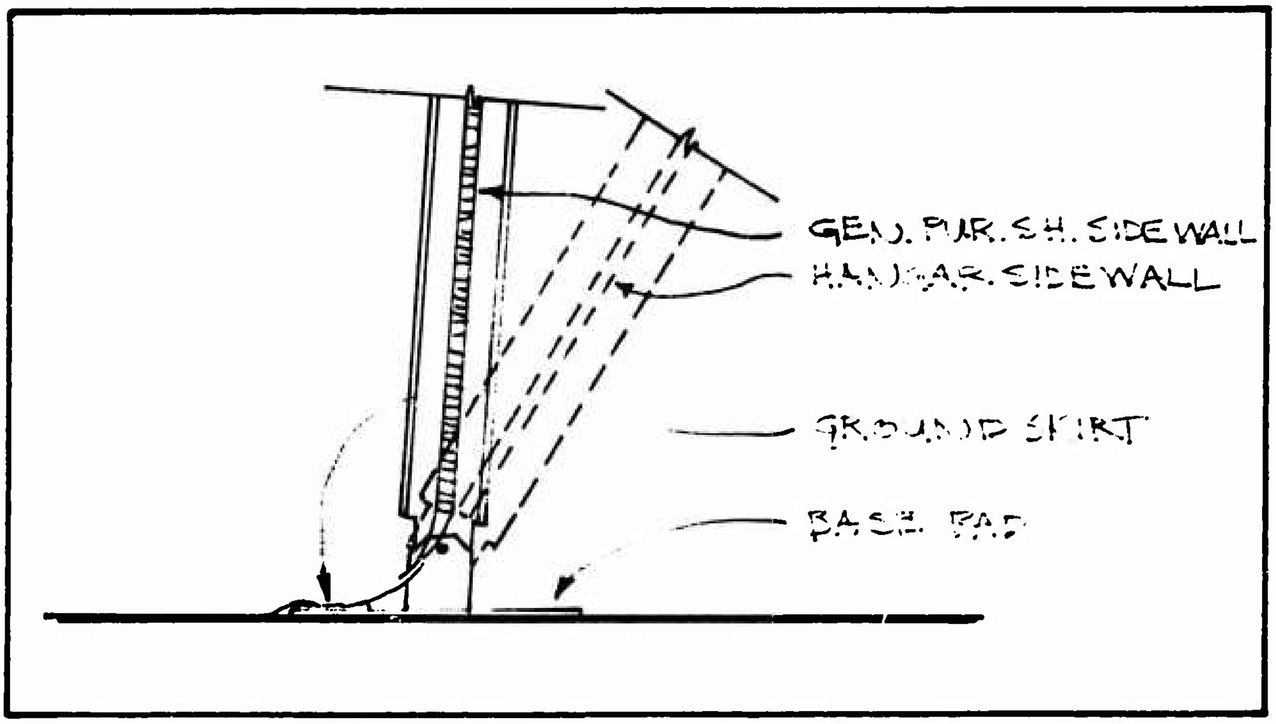

Figure 93. Ground Condition

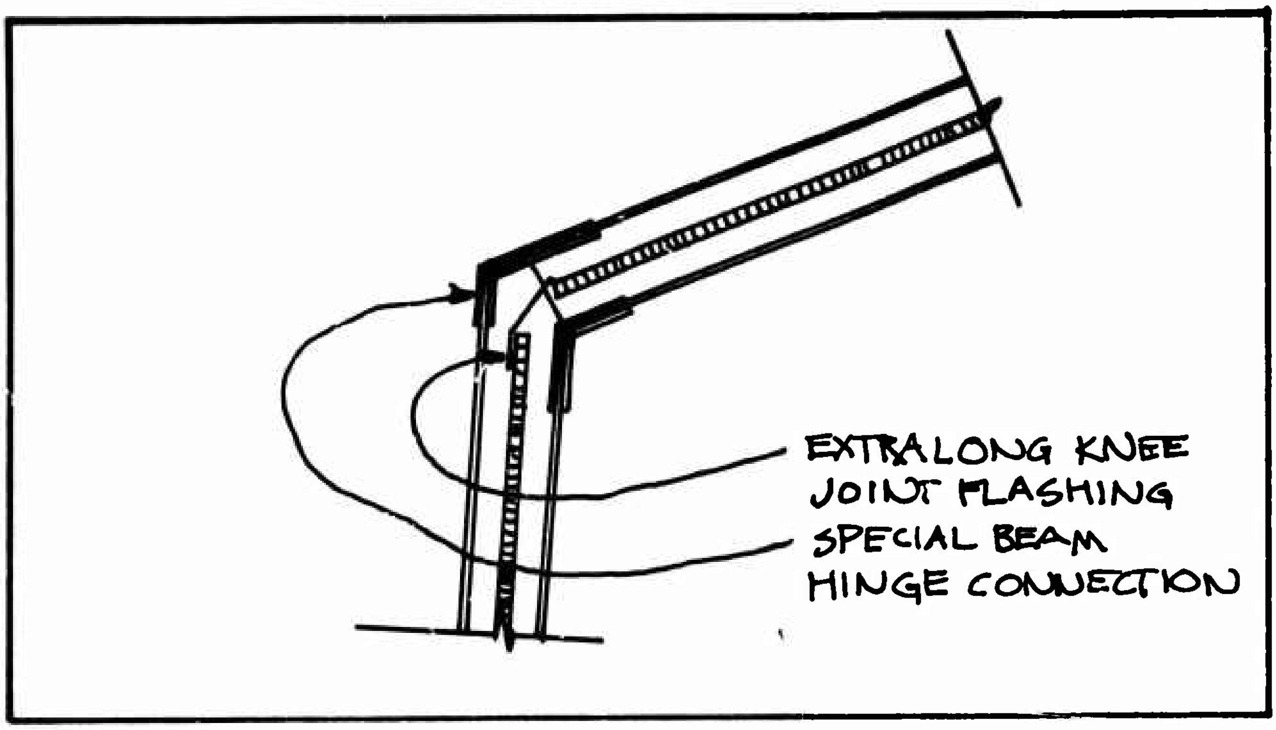

Figure 94. Knee Joint with Special Beam and Panel

b. The other method of making this knee joint transition consists of using all standard hangar beams and panels. A "hinge link" would be added between the top beam hinges to achieve the angle required. Also the first roof panel could be flashed to the side wall panel by inserting a knee flashing strip to provide the additional length required. (Figure 95)

3. <u>End Wall</u>

The end wall for the General Purpose Shelter, because of its configuration, would necessitate the use of special components. (Figure 96)

The impact of special end wall components can be minimized by use of fabric flashing to close-out side wall and door head openings. (Figure 96, left side)

A completely hard panel end wall can be achieved by use of special panels at side wall and door head openings. (Figure 96, right side)

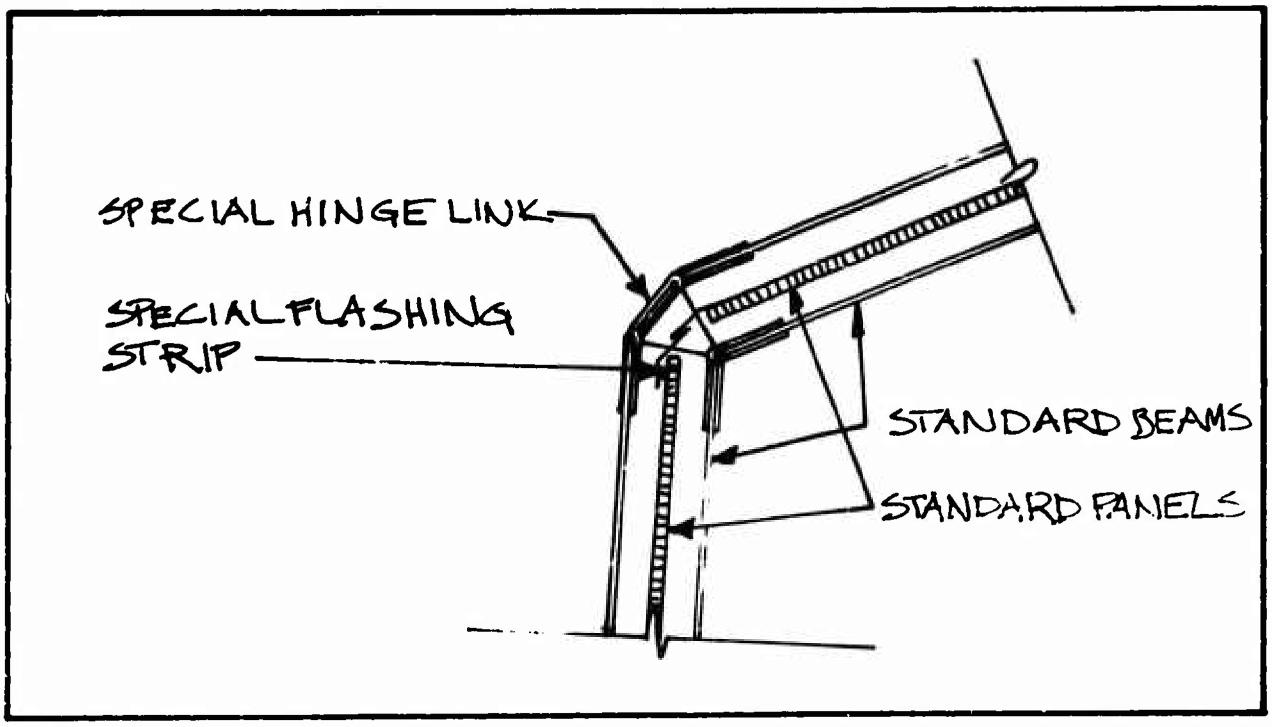

Figure 95. Knee Joint with Standard Beam and Panel

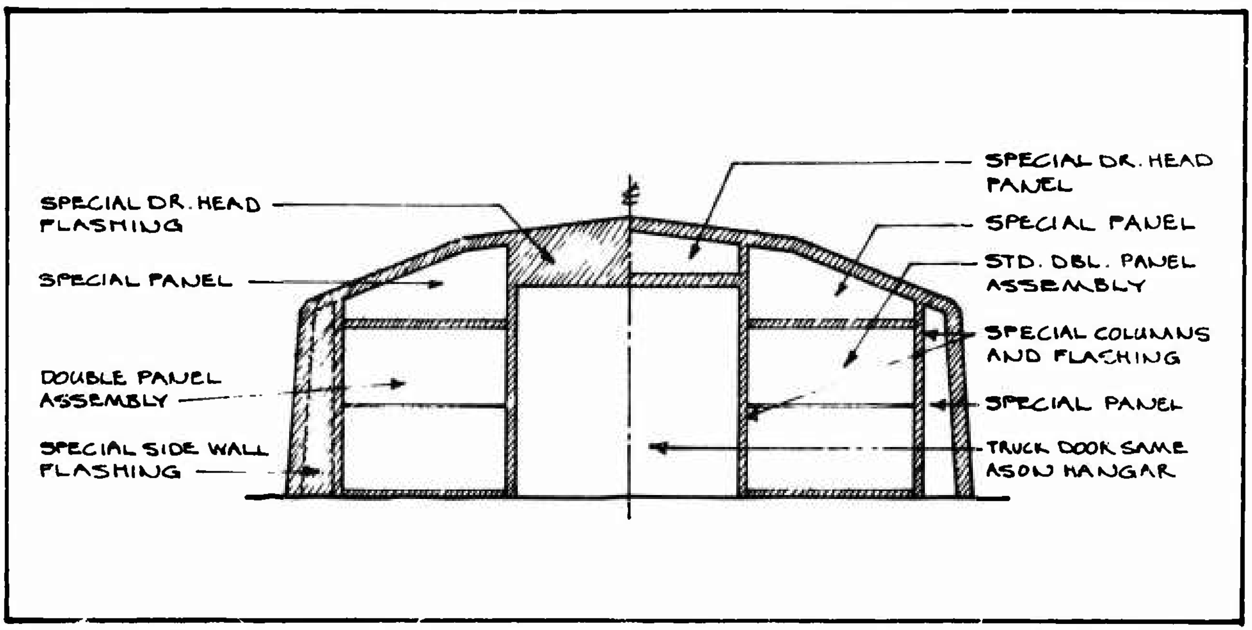

Figure 96. End Wall

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VI

PROTOTYPE ARCHES

Prototype arches of both the Beam and Panel and the Beam, Purlin and Sheathing concepts were fabricated. The Beam and Panel concept is described in Section IV, Paragraph E, and the Beam, Purlin and Sheathing concept is described in Section IV, Paragraph D.

A. DEVELOPMENT OF COMPONENTS

Development of components used in the prototype arches is covered in this paragraph.

Further refinements made on many of these items are covered in discussions of the first and second full size hangar prototypes in Sections VII and VIII respectively.

1. Structural Schematic

Identification of the components that make up a Beam and Panel arch, and a Beam, Purlin and Sheathing arch is shown in Figure 97.

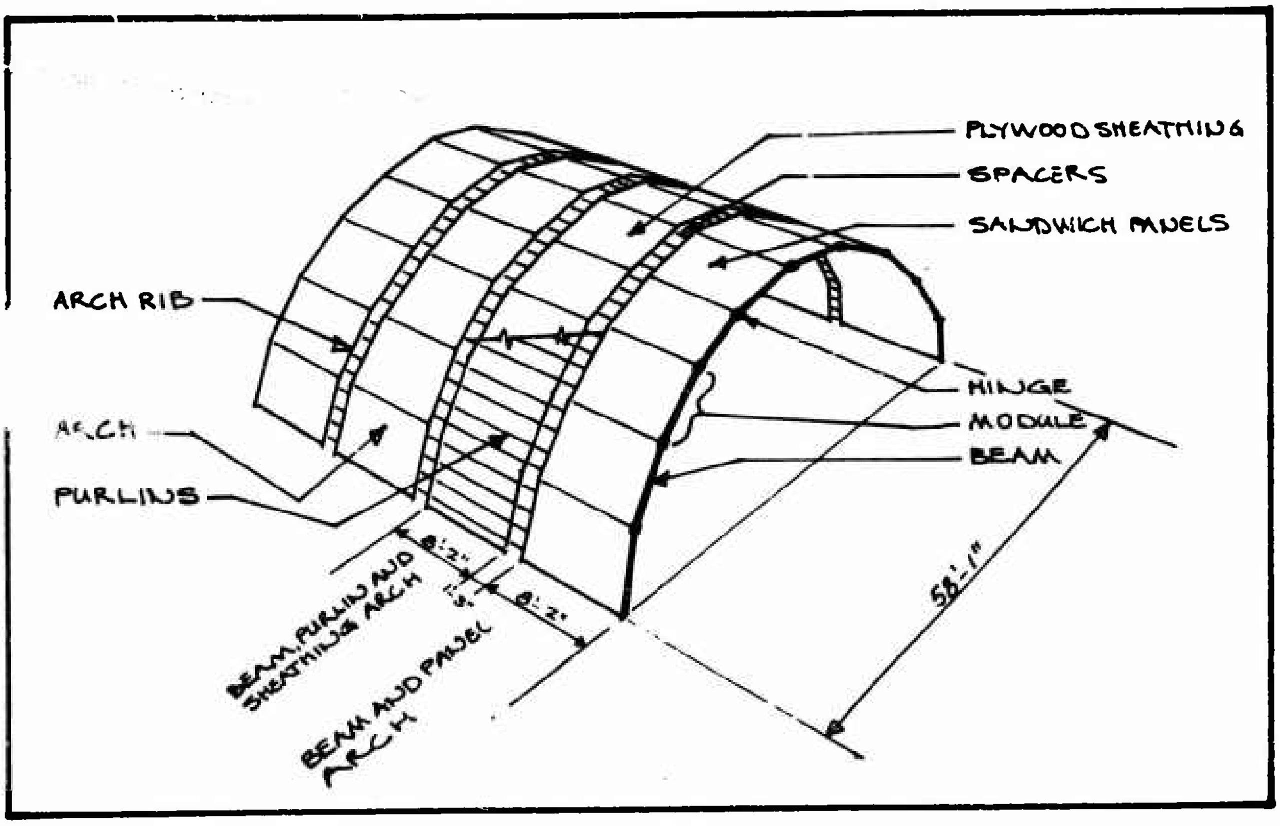


Figure 97. Structural Schematic

2. Structural Loadings

Structural analysis was performed, using the Matrix method and the results were verified by Strain Energy Techniques. The details of analysis are in Appendix A.

The hangar structure was analyzed for the effect of wind loads, full snow loads and half snow loads.

a. The effect of wind forces on the structure is as indicated in Figure 98 and intensity of loading varies from zone to zone.[1]

Dynamic pressure:

$$q = 0.0256\ V^2 = 10.8 \text{ lbs/sq ft}$$

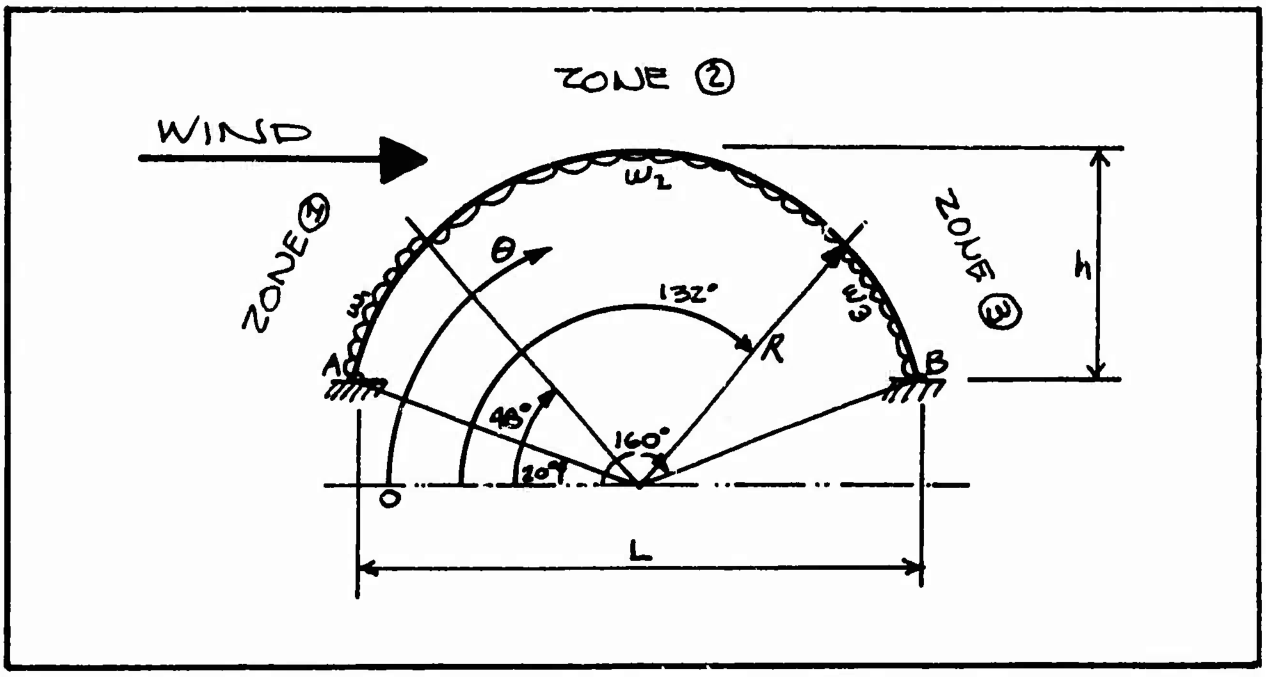


Figure 98. Wind Load Distribution on Structure

Equivalent static pressure is:

$$p = cd \times q$$

For $20° < \theta < 48°$, $cd_1 = 0.52$

For $48° < \theta < 132°$, $cd_2 = 1.07$

For $132° < \theta < 160°$, $cd_3 = 0.5$

[1]Transactions of ASCE, Vol. 126 II, p. 1153, 1961.

Therefore:

$$w_1 = cd_1 \times q = 0.52 \times 10.8 = 5.6 \text{ lbs/sq ft}$$

$$w_2 = cd_2 \times q = 1.07 \times 10.8 = 11.55 \text{ lbs/sq ft}$$

$$w_3 = cd_3 \times q = 0.50 \times 10.8 = 5.4 \text{ lbs/sq ft}$$

The arch rib is made of ten straight "I" section beams. Panels, nominally 4' x 8', are attached to arch ribs by means of two camlocks at each end. Therefore loads from panels are transferred to the ribs by means of locks as point loads, and these loadings are shown in Figure 99.

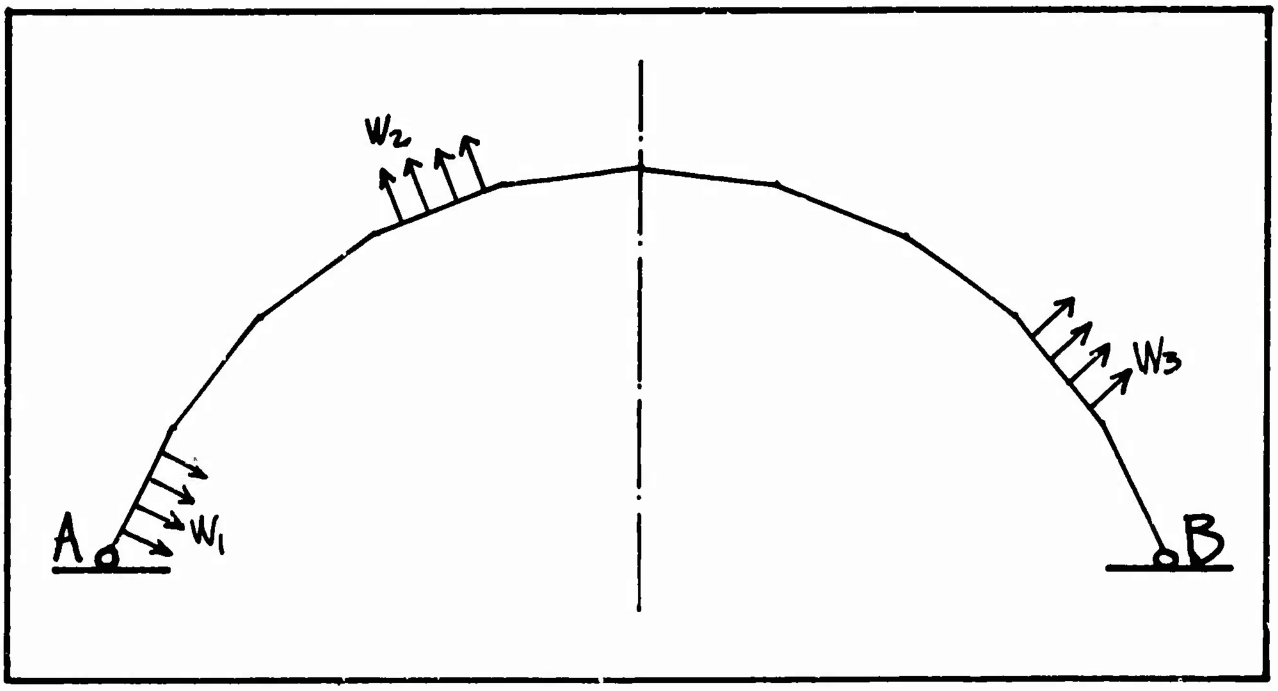


Figure 99. Load on Camlocks

The structure is designed for 65 mph winds and a 90 mph gust. Therefore the appropriate loadings are as follows:

$$W = w \times \frac{(8'\text{-}2" + 1'\text{-}3"^{*})\ (3'\text{-}9\ 1/2")}{4} = 8.88w$$

* Including effect of spacers

For different wind velocities, wind and camlock loads are shown in Table II.

TABLE II. Wind Loads and Corresponding Cam Lock Loads

M.P.H. WIND VEL.	LBS.SQ.FT				POUNDS		
	q	w_1	w_2	w_3	W_1	W_2	W_3
65	10.8	5.6	11.55	5.4	49.7	102.5	48.0
90	20.7	10.75	22.2	10.35	95.5	197.2	92.0

b. Two cases of snow loading on the hangar structure were investigated:

Case I: Snow or ice forming on all of the structure. (Figure 100)

Case II: Snow or ice forming only on half of the structure. (Figure 101)

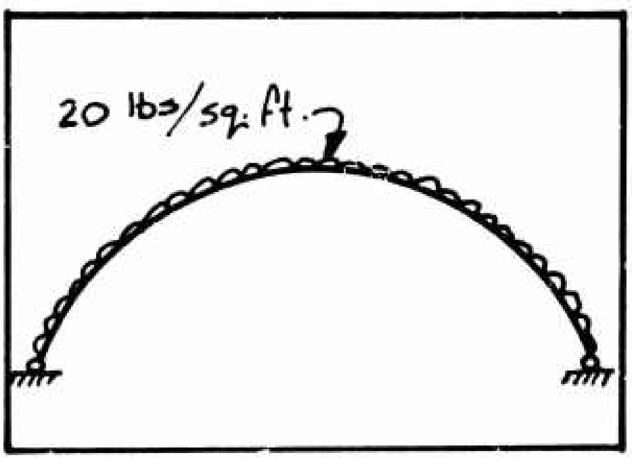


Figure 100. Full Snow Load

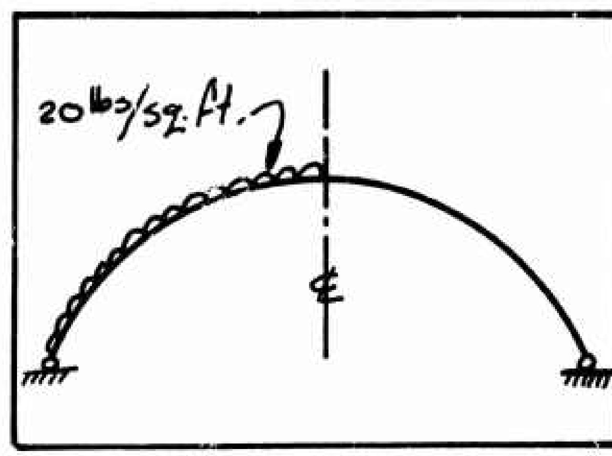


Figure 101. Half Snow Load

Maximum arch rib moments for wind and snow load conditions are shown in Table III.

TABLE III. Maximum Moments in Arch Ribs

LOADING CONDITION	MAXIMUM MOMENT LB.IN.
65 mph wind	-42099
90 mph wind	-80758
Full snow	40316
Half snow	79242

3. Arch Rib Beam

Two "I" beam sizes were analyzed that possessed the required structural properties.

a. The first beam was a standard 3.43 lb/ft 6061-T6 alloy aluminum "I" beam. (Figure 102)

Vertical and horizontal deflections and maximum beam stresses for wind and snow loadings are shown in Figure 103.

b. The second beam was a special beam designed in an attempt to reduce the overall hangar weight. It weighed 2.58 lbs/ft and would be made of 6061-T6 alloy aluminum. (Figure 104)

Arch deflections and maximum beam stresses are shown in Figure 105.

Aluminum with a 6061-T6 alloy has a yield strength of 35,000 psi and a working stress of 25,000 psi and was adopted. Therefore the factor of safety for the two beams discussed above are:

a. Standard 3.43 lb/ft beam, 65 mph wind = $\frac{25000}{9435}$ = 2.65

Standard 3.43 lb/ft beam, 90 mph wind = $\frac{25000}{16648}$ = 1.5

b. Special 2.58 lb/ft beam, 65 mph wind = $\frac{25000}{12600}$ = 1.98

Special 2.58 lb/ft beam, 90 mph wind = $\frac{25000}{23000}$ = 1.09

Due to the low factor of safety and the difficulties involved in purchasing the special 2.58 lb/ft beam, the standard, 3.43 lb/ft beam was chosen for use on the first prototype hangar arches.

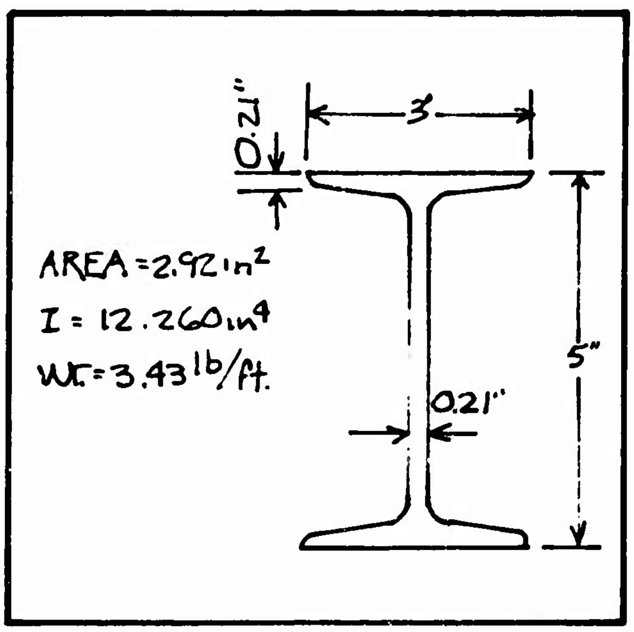


Figure 102. Standard "I" Beam

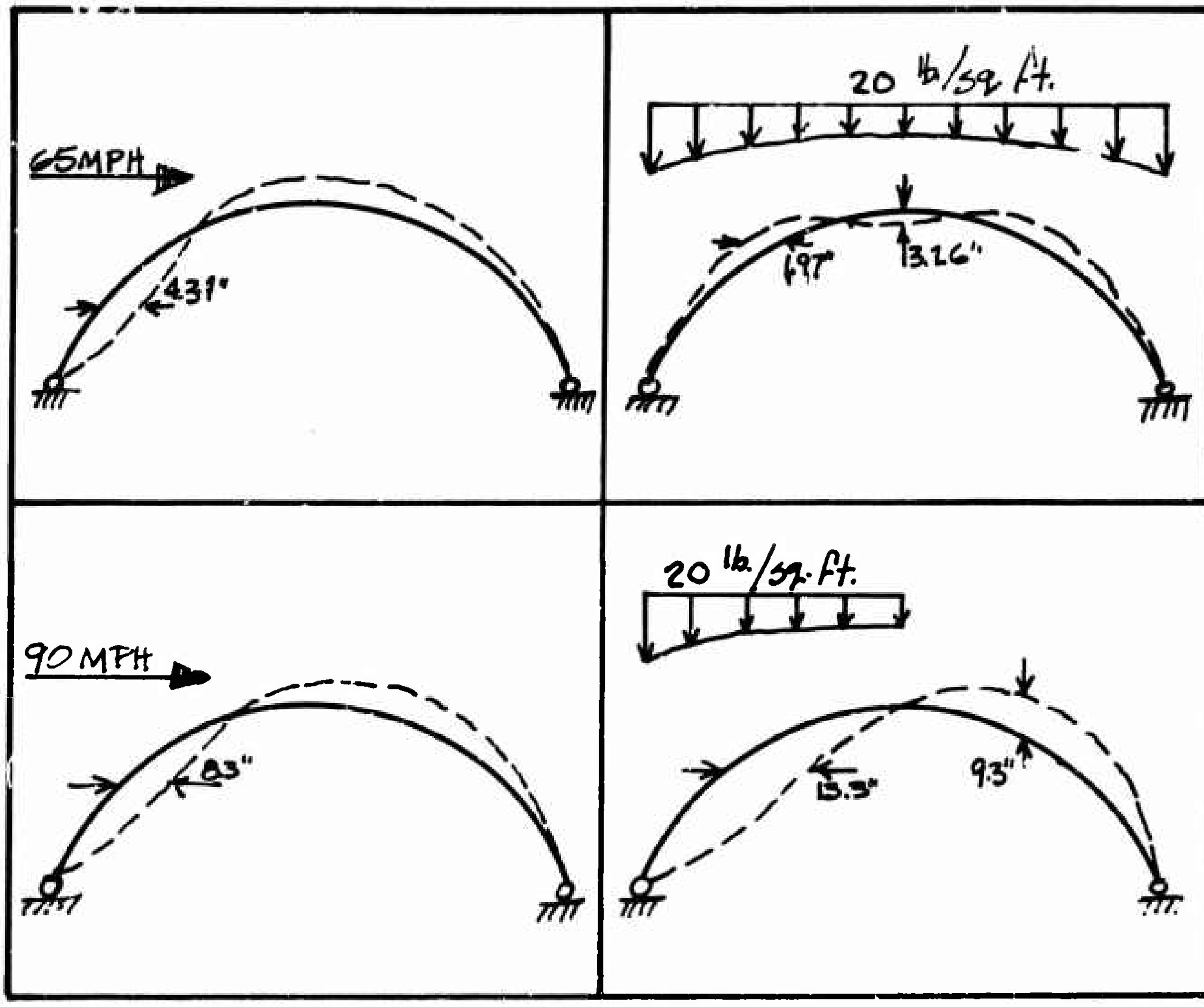


Figure 103. Standard Beam-Arch Deflections

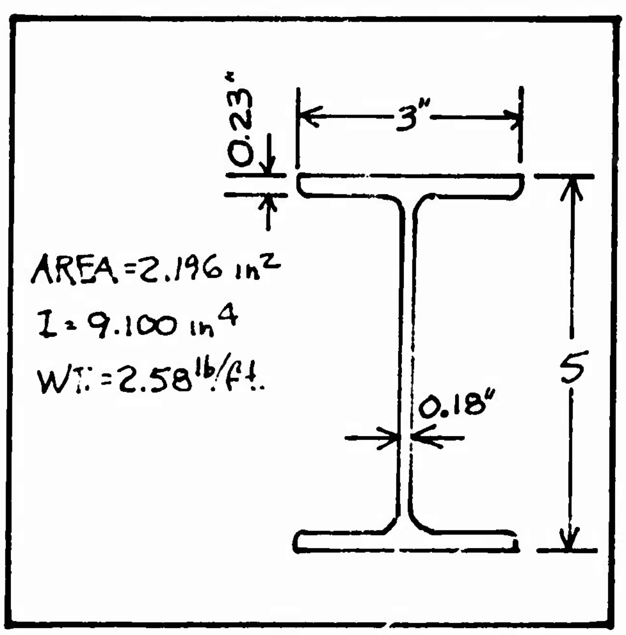


Figure 104. Special "I" Beam

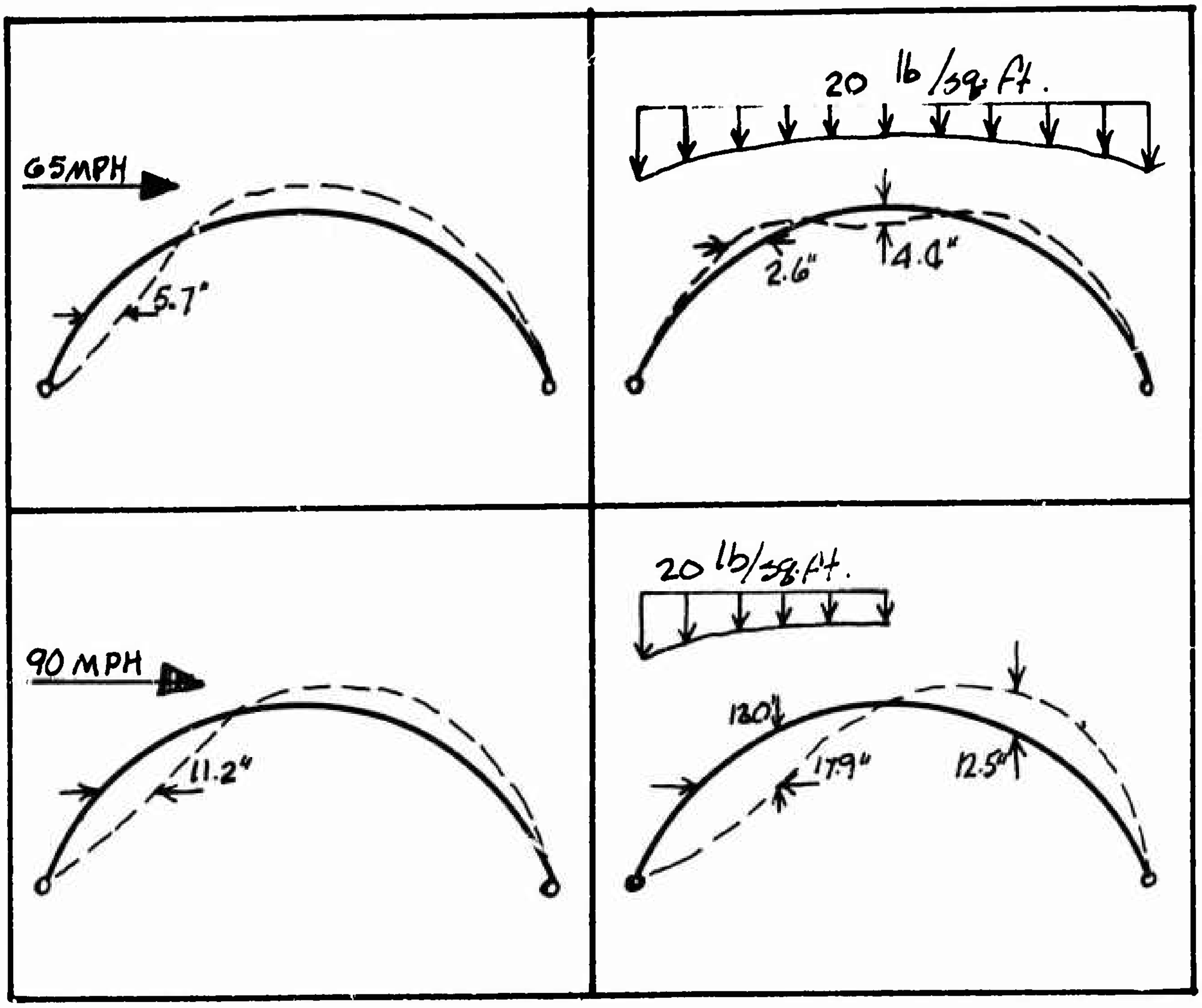


Figure 105. Special Beam-Arch Deflections

4. Hinges

Two types of arch beam hinge connectors were designed and tested.

a. The first type was a "strap" hinge made up from flat steel plates which have slots punched into them before they are bent over to form a hinge leaf. (Figure 106)

Slots are cut into beam ends and the hinge leaves are slid over the beam flanges. The inside hinge leaf strap "egg-crates" with the beam web, and the hinge leaf is bolted to the beam flange using beveled washers. (Figure 107)

Advantages of this type of hinge are:

1.) a minimum amount of steel is required because of efficient distribution of stresses and

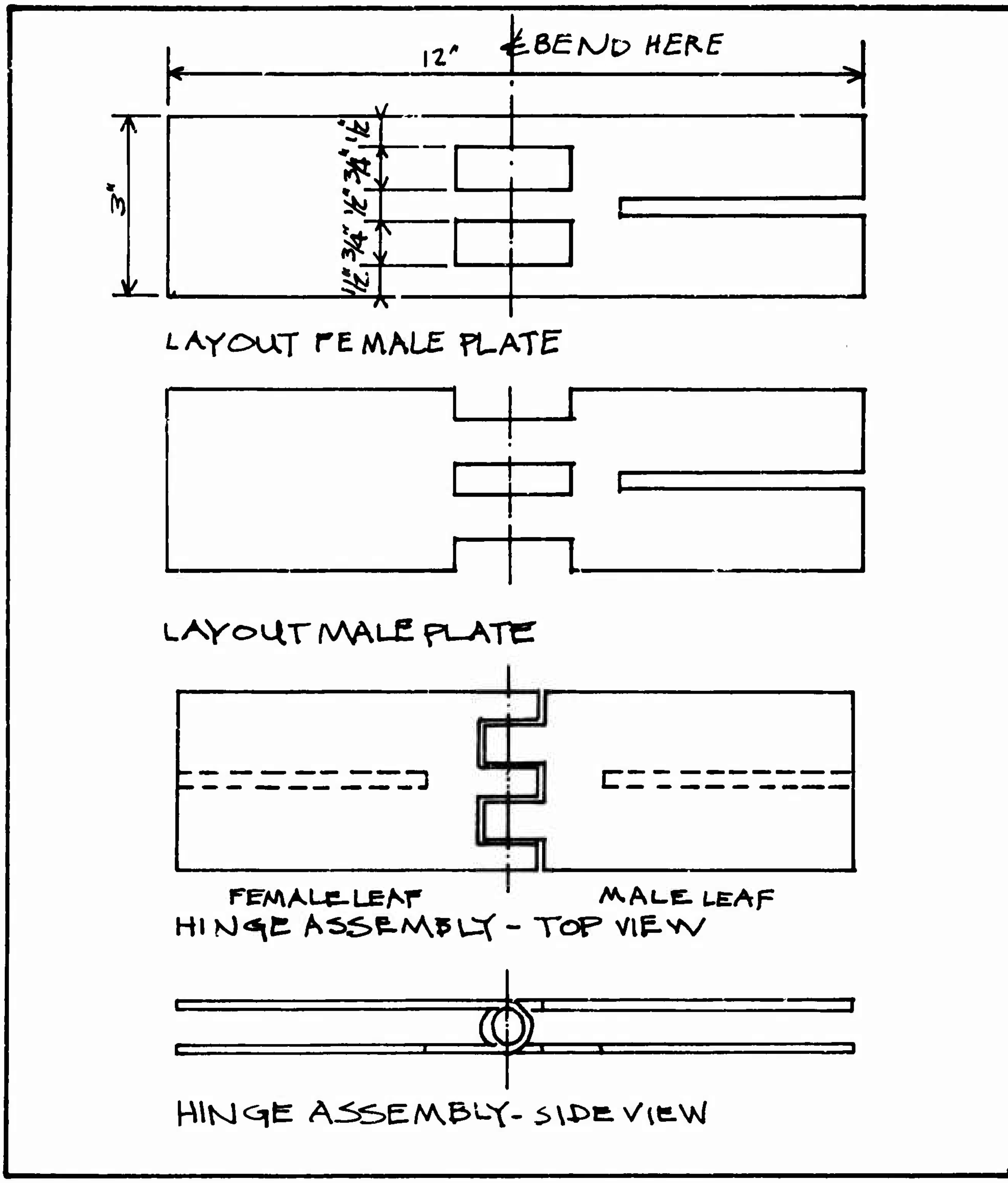


Figure 106. Strap Hinge

2.) the attachment bolts are placed in double shear thus reducing stresses on the bolt and providing even bearing on the beam flanges.

The disadvantage that made this hinge impractical was the difficulty involved in providing the close tolerances required

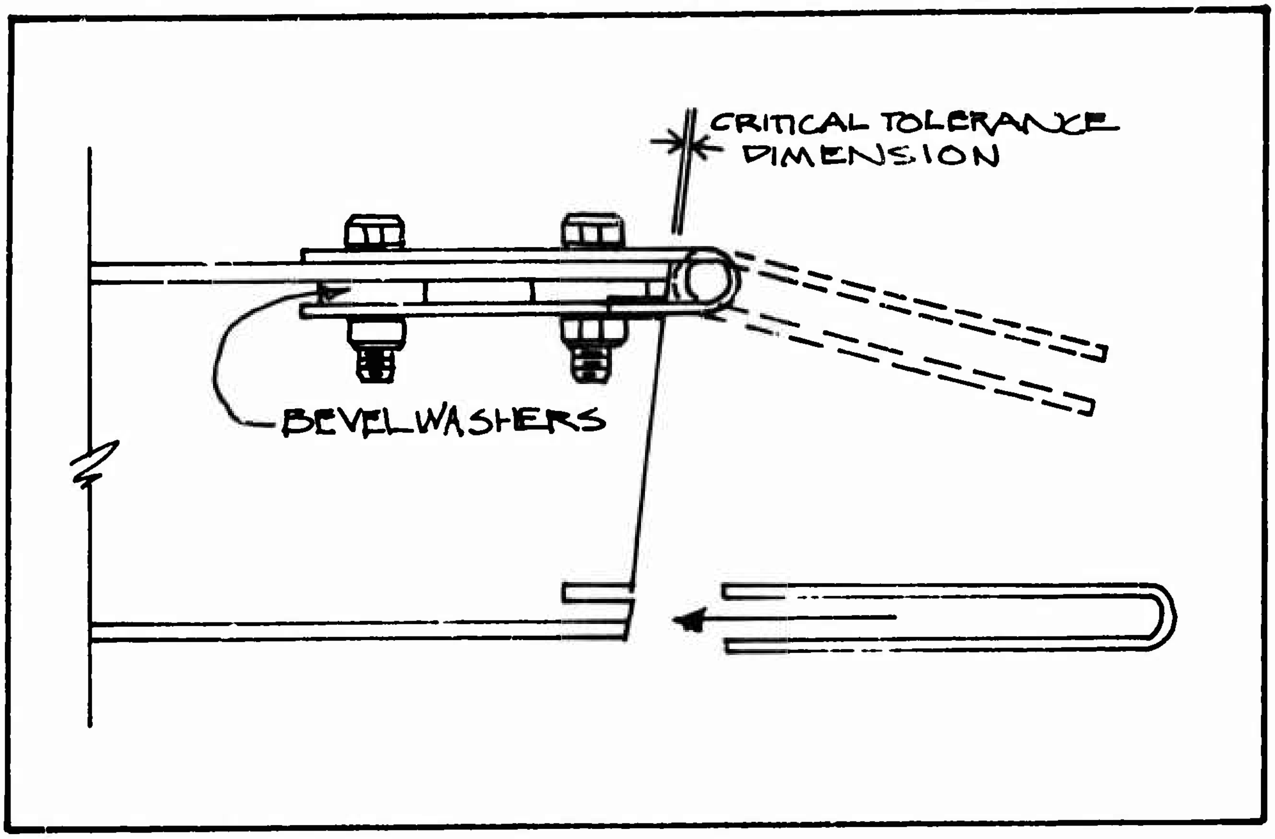


Figure 107. Strap Hinge Assembly

between hinge noses and beam flanges. Slight inaccuracies in cutting the beams and mounting the hinges result in a joint with too much play. This play would not result in a failure of the beam connection but would amplify deformation of the arch when loaded.

b. The second type of hinge developed was made from steel forgings. The first hinges of this type tested were simply machined from type 1020 steel and were not heat treated. (Figure 108)

They were mounted on two aluminum beams and tested with strain gauges mounted on the hinge knuckles. Although the stress was not carried to the yield strength of the steel, the form of the stress-strain curve indicated an undesirable deformation before yield. (Figure 109)

The second hinges tested of this type were forged and machined using C-1045 steel hardened to a Rockwell of 34. (Figure 110) The flexure test, mentioned above, was repeated for these hinges. They were loaded up to 24,000 lbs. without any sign of yielding. (Figure 109) Since the design load across a hinge at a 90 mph wind is 14,200 lbs., a more than adequate factor of safety is assured. Dimensions of this hinge, which was used on the prototype hangar arches, are shown in Figure 111.

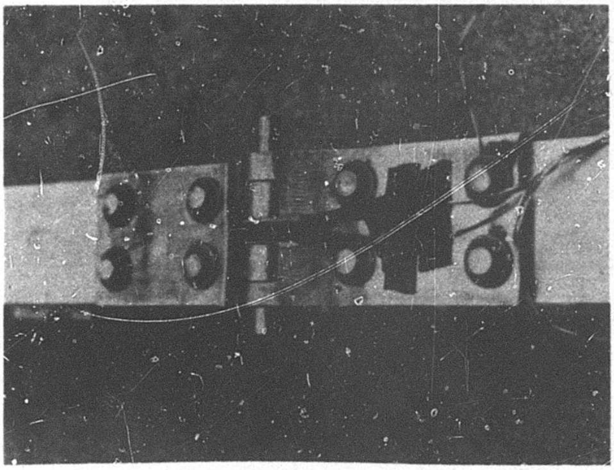


Figure 108. Machined Hinge

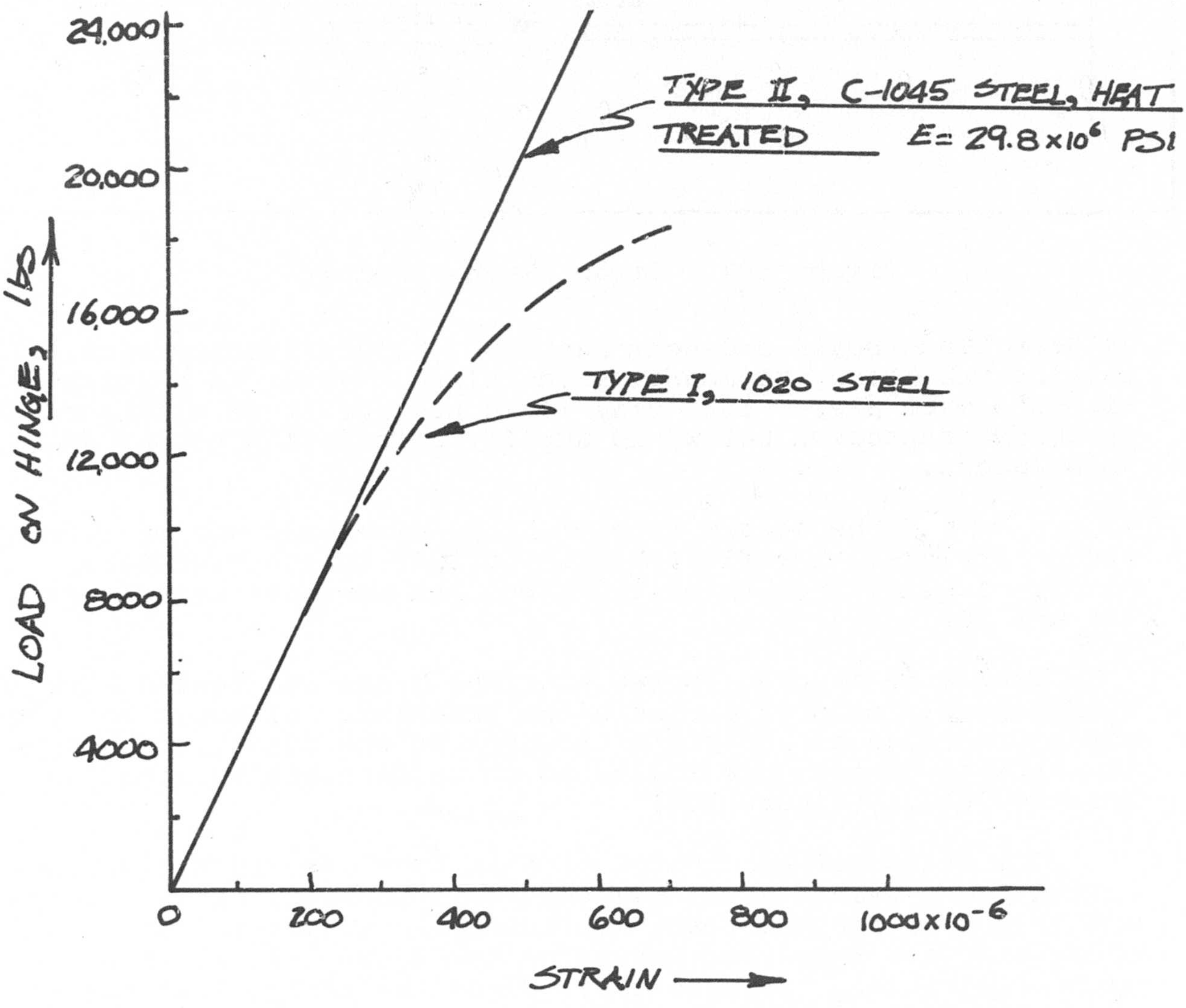


Figure 109. Load Characteristics of Hinge Connectors

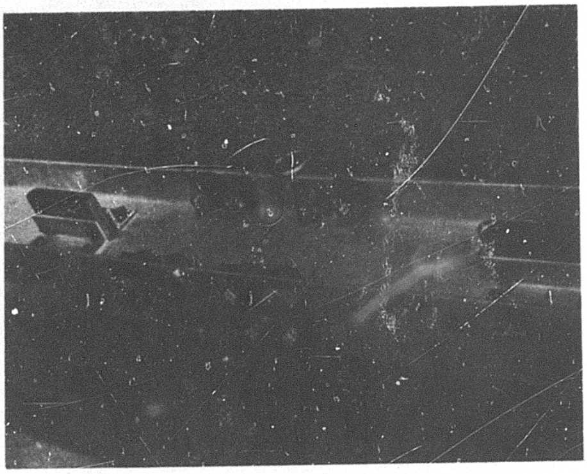


Figure 110. Forged Hinge

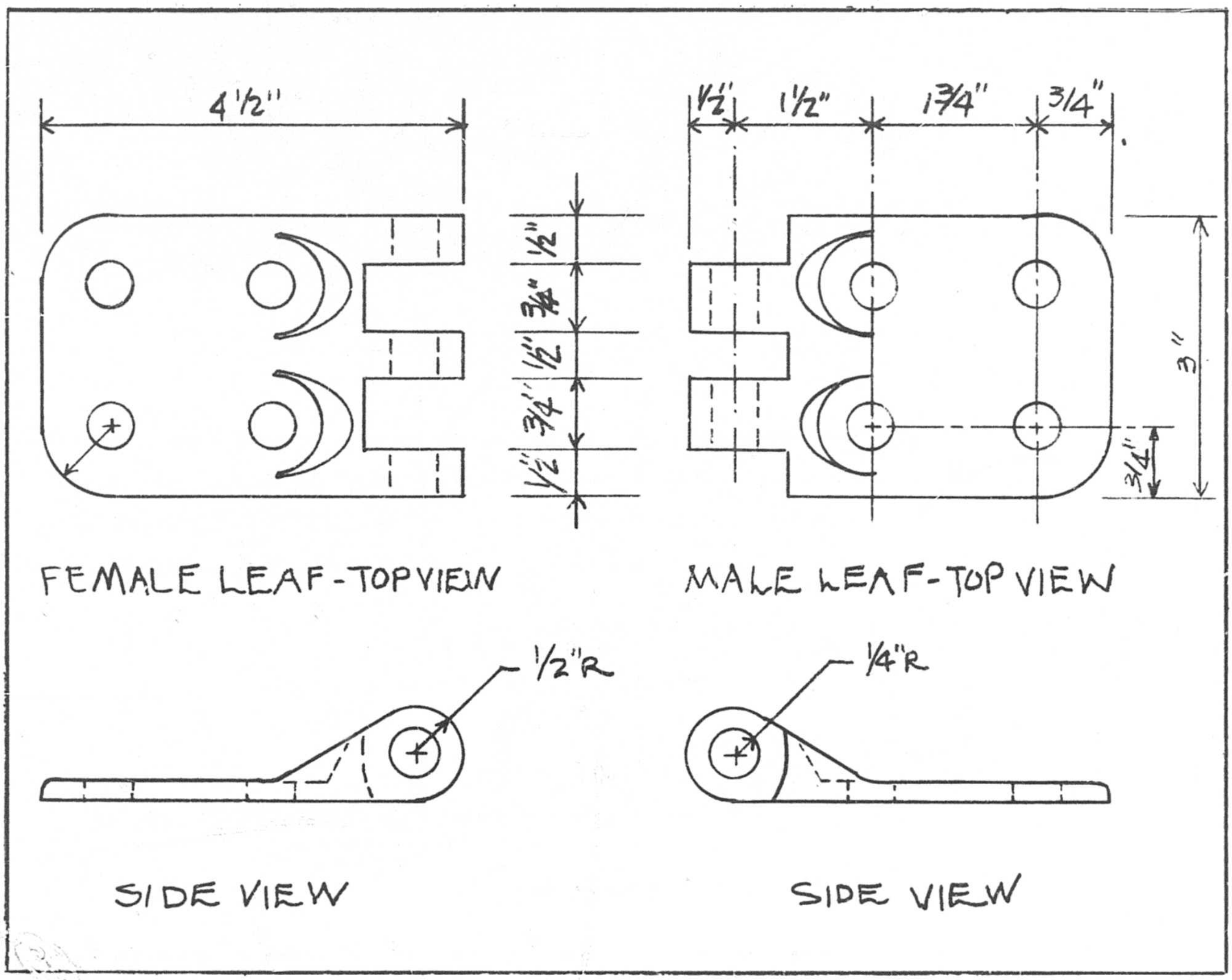


Figure 111. Hinge Dimensions

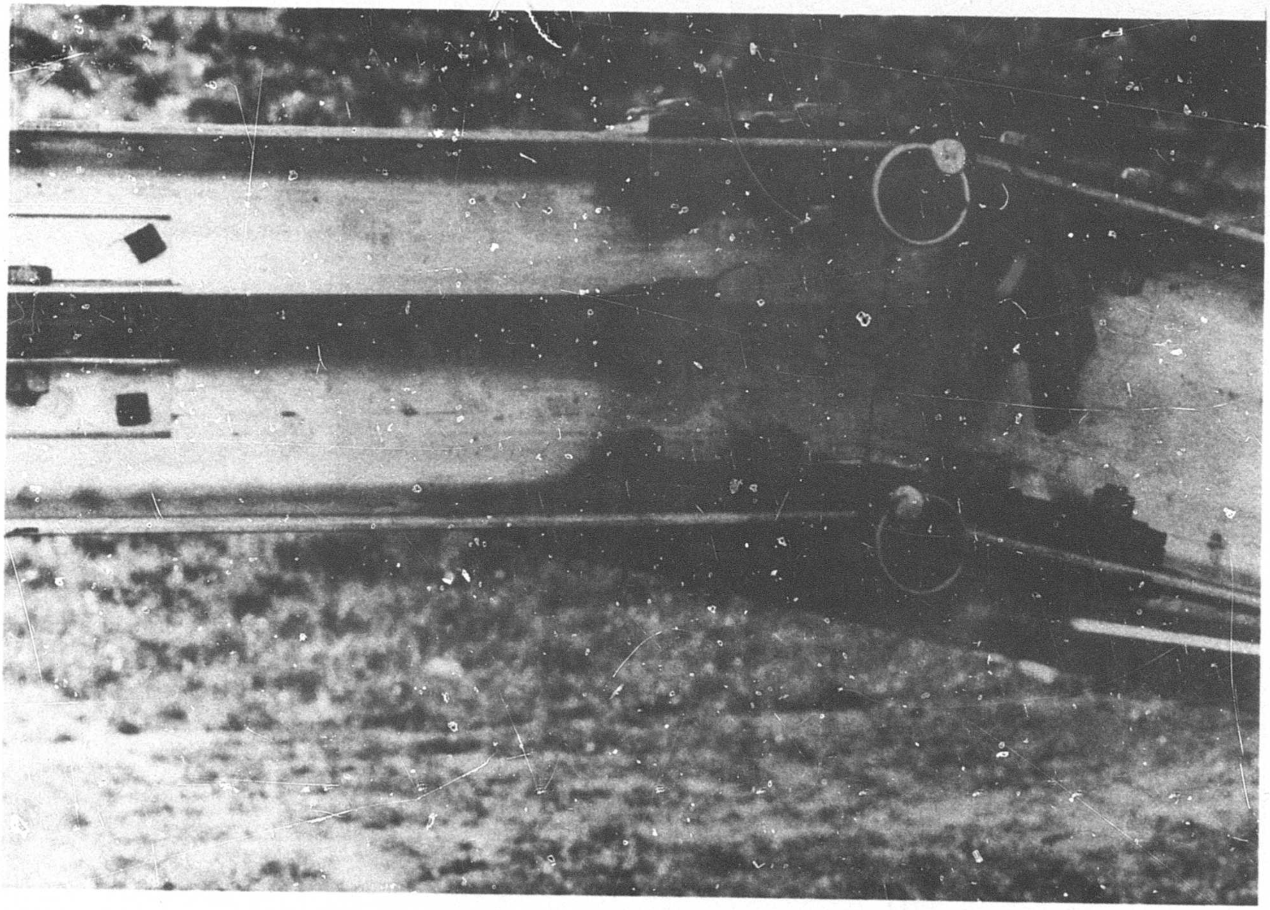


Figure 112. Steel Spacer

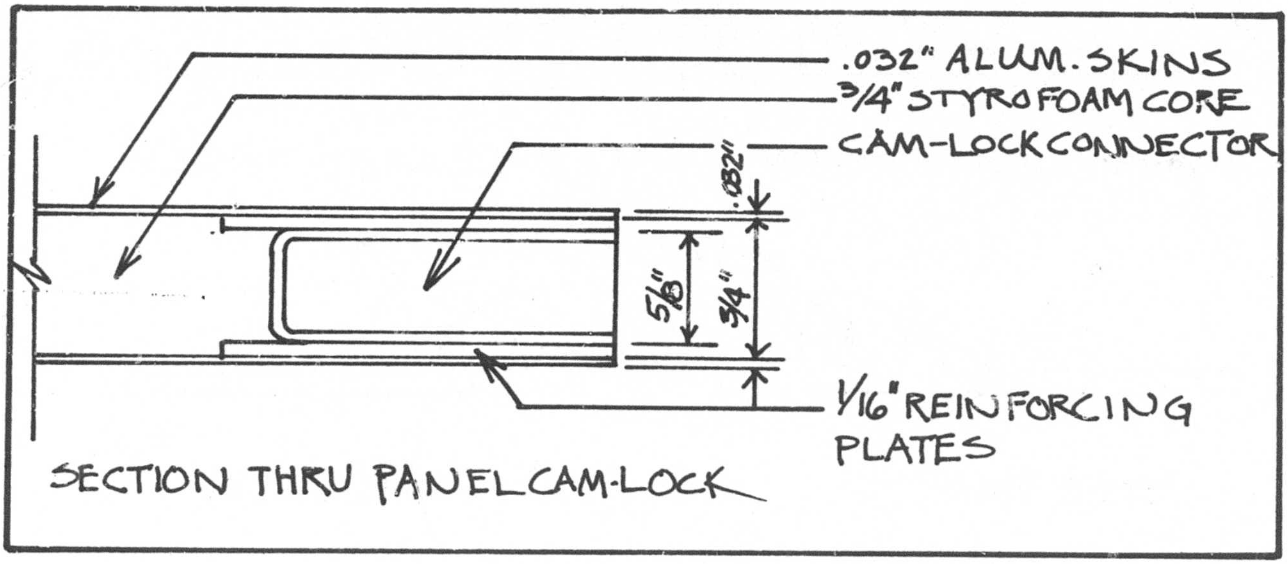


Figure 113. Panel Camlock

5. Spacers

Requirements for the arch to arch connector spacers (Figure 97) are:

(1) They should be permanently attached to the arch beams and hinged to fold into the beam to permit efficient stacking of beams for packaging.

(2) They should be variable in length in order to adjust for changing arch to arch dimensions caused by irregular terrain.

(3) They must lock to adjacent arch rib beams and be capable of resisting the weight of men using them as ladder rungs. They must also resist a 500 pound maximum compression load at the arch ridge due to wind loading on the hangar end wall.

A steel spacer was designed (Figure 112) and used on the prototype arches. It incorporated a threaded portion for achieving variations in length and a spring-loaded locking device for locking to adjacent arch rib beams.

A much less complex, all aluminum, spacer was developed for use on the first full size prototype hangar. (Figure 153)

6. Panels

Preliminary analysis indicated that a 5/8" thick panel with .046" thick aluminum facing sheets would be required. A 3/4" panel thickness was found to be practical in that skins could be lighter and a 5/8" thick "camlock" type connector could be incorporated in the panel edge. This camlock, manufactured by Simmons Fastener Corporation under the trade name of "Dual-Lock", was found to be a very efficient means of attaching panels to beams in terms of strength and ease of operation. (Figure 113)

Materials investigated as potential sandwich panel components were:

(1) Skins materials
  (a) .050" thick aluminum
  (b) .040" thick aluminum
  (c) .030" thick aluminum
  (d) 28 gauge stainless steel

(2) Adhesives
  (a) 3M #2226 contact adhesive
  (b) Dow epoxy #QX3828 and DEH 14
  (c) Dow epoxy Der 330 and DEH 14
  (d) 3M epoxy #2216

(3) Core materials
    (a) Dow 6 pound density Styrofoam
    (b) Dow 2-1/2 pound density Styrofoam
    (c) Dow PVC Robb Core
    (d) Stolle 1-1/2 pound density Styrofoam

Test panels 1' wide x 8' long were made of combinations of the above mentioned materials. They were loaded with 16 lb/sq ft and midspan deflections were read at regular intervals for 48 hours. (Figure 114) Data on these panels and comparative maximum deflections are shown in Table IV.

TABLE IV. COMPARATIVE PANEL TEST DATA

Panel No.	Skin Material	Core Material	Adhesive	Deflection In.
1	.050" al	5/8" 6# foam	3M #2226	1-1/2
2	.050" al	5/8" 6# foam*	3M #2226	1-3/16
3	.050" al	5/8" Robb Core	Dow #QX38281	Failure
4	28 ga. st. stl.	5/8" Robb Core	Dow #QX38281	Failure
5	.050" al	3/4" 2-1/2# foam	3M #2226	5/8
6	.050" al	3/4" 2-1/2# foam	Dow DER 330	5/8
7	.040" al	3/4" 2-1/2# foam	Dow DER 330	3/4
8	.032" al	3/4" 2-1/2# foam	Dow DER 330	15/16
9	28 ga. st. stl.	3/4" 2-1/2# foam	Dow DER 330	13/16
10	.050" al	3/4" 2-1/2# foam	3M #2226	15/16

*The core for this panel was reinforced with a 5/8" x 5/8" x 1/8" aluminum channel.

Figure 114. 1' x 8' Panel Tests

Conclusions reached from these comparative tests were:

(1) The addition of reinforcing channels in center of panel cores does not add significantly to the strength of a thin panel.

(2) The stretch-formed 5/8" PVC "Robb Core" material used in panels 2 and 3 was experimental and only available in 2' lengths. The panels failed due to compressive skin buckling at the points where the core materials were discontinuous.

(3) The 3/4", 2-1/2 lb. density Styrofoam used in panel 5 was an improvement over the 5/8" 6 pound density Styrofoam used in panel 1.

(4) For normal temperature conditions, the far more economical neoprene contact type (#2326) adhesive performed as well as the epoxy type adhesives.

(5) The .032" al. skins are adequate. Also they are lighter and less expensive than the stainless steel panel skins.

Consequently the panels for the prototype arch were designed incorporating: 3/4", 2-1/2 pound density Styrofoam, 3M #2226 contact adhesive and .032" aluminum skins. The configuration and details of this panel are shown in Figure 115. The 3M #2226 adhesive was changed at the recommendations of the panel manufacturer to Pittsburg Plate Glass #426 neoprene adhesive. This adhesive was more compatible with the manufacturer's fabricating techniques, and comparative tests indicated that both adhesives possessed equivalent structural characteristics.

Static dynamic and thermal tests were performed on full size panels incorporating Styrofoam, paper honeycomb and balsa wood cores. These tests are discussed in Section VI, Para. D.

7. Purlins and Plywood Sheathing

An aluminum purlin and plywood sheathing system was investigated as an alternative to the rigid panels. (Figure 97) The rib beams, hinges and spacers are the same for both arch designs.

The Beam, Purlin and Sheathing concept, discussed in Section IV, Paragraph D, was the basis for this investigation of the purlin and plywood sheathing system.

A detailed comparison of the purlin-plywood and the panel systems can be seen in Figure 116. Two plywood panels are attached to four aluminum purlins which are, in turn, attached at each end to arch beam sections. The purlins attach to the

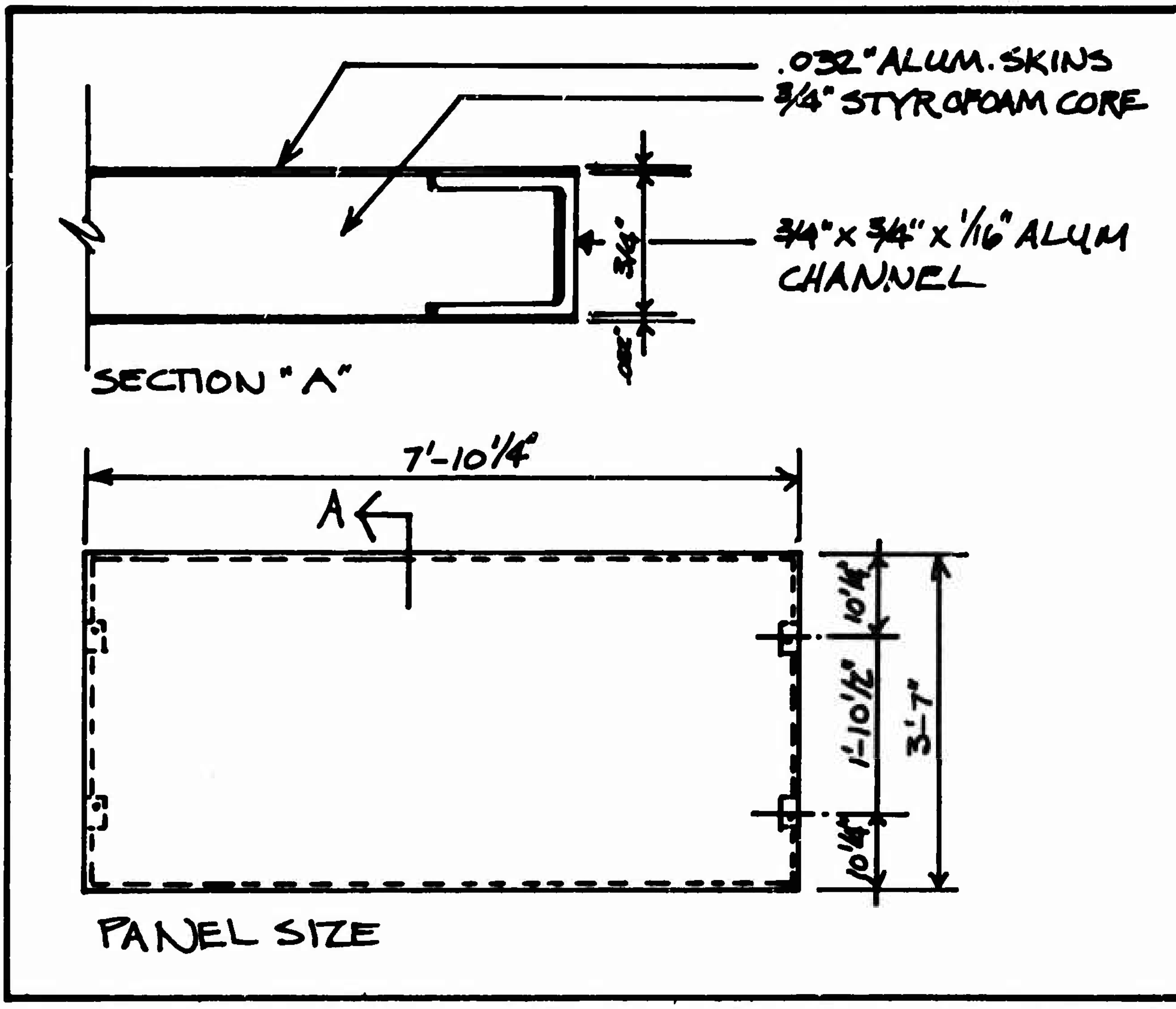


Figure 115. Prototype Arch Sandwich Panel

arch beams by means of the spring-loaded clip device shown in Figure 117. This device was difficult to operate and was modified to incorporate a spring and a clip on the purlin ends. (Figures 118 and 119) Note that the spacer locks to the beam in the same manner as the purlins.

Each sheet of plywood attaches to the purlins at four places with "Velcro" straps as shown in Figures 116 and 117.

Compared to the sandwich panel system, the purlin and plywood system has several deficiencies. To be comparable in weight to the sandwich panels, 1/4" plywood would have to be used. 1/4" plywood is not strong enough to carry the weight of men walking on them.

Due to promising developments on the rigid sandwich panels and deficiencies noted in the purlin and plywood development, the sandwich panel system held the most promise for carrying

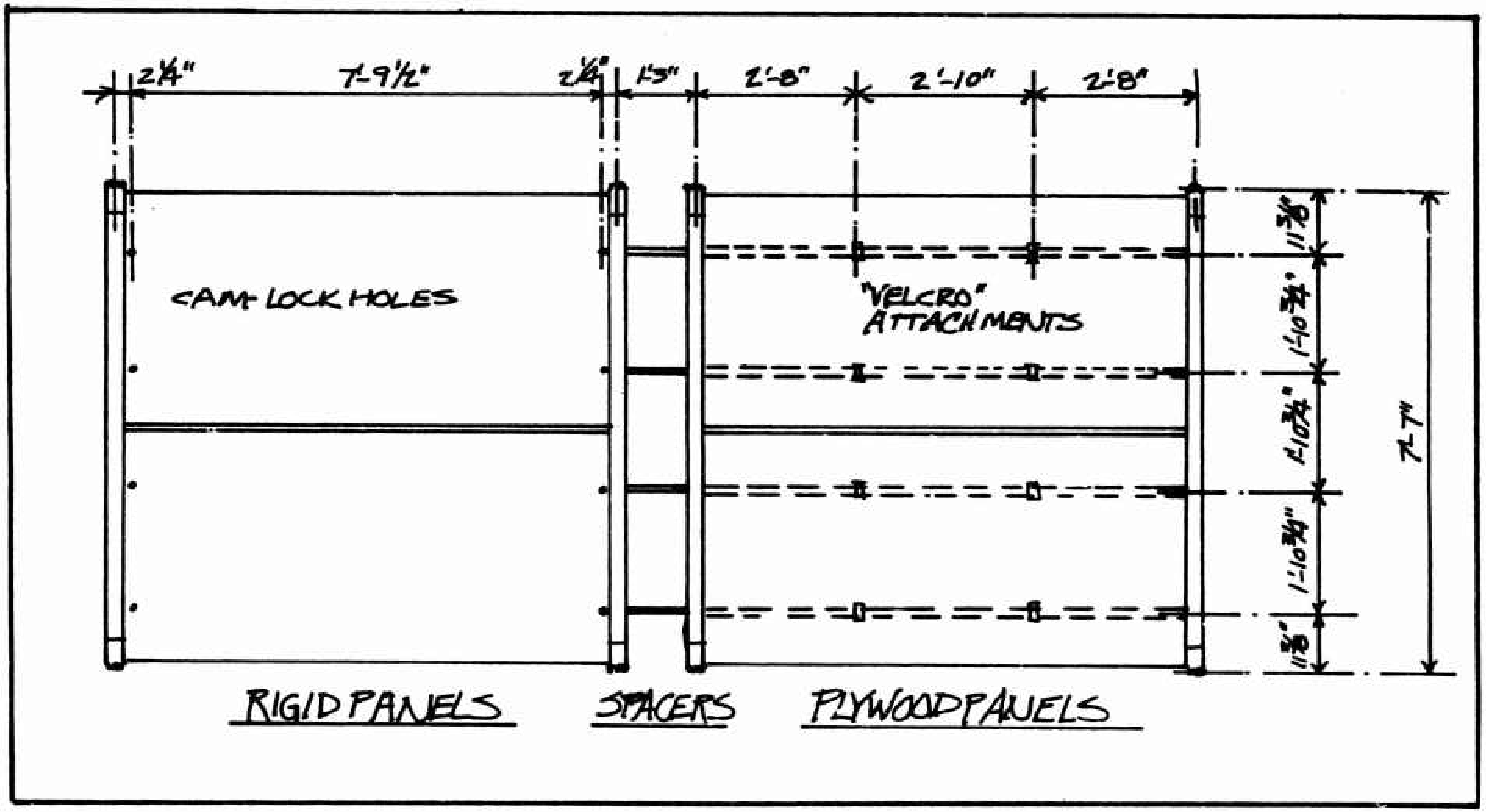


Figure 116. Comparison of Panel Systems

through to the complete arch static tests covered in Paragraph C of this Section.

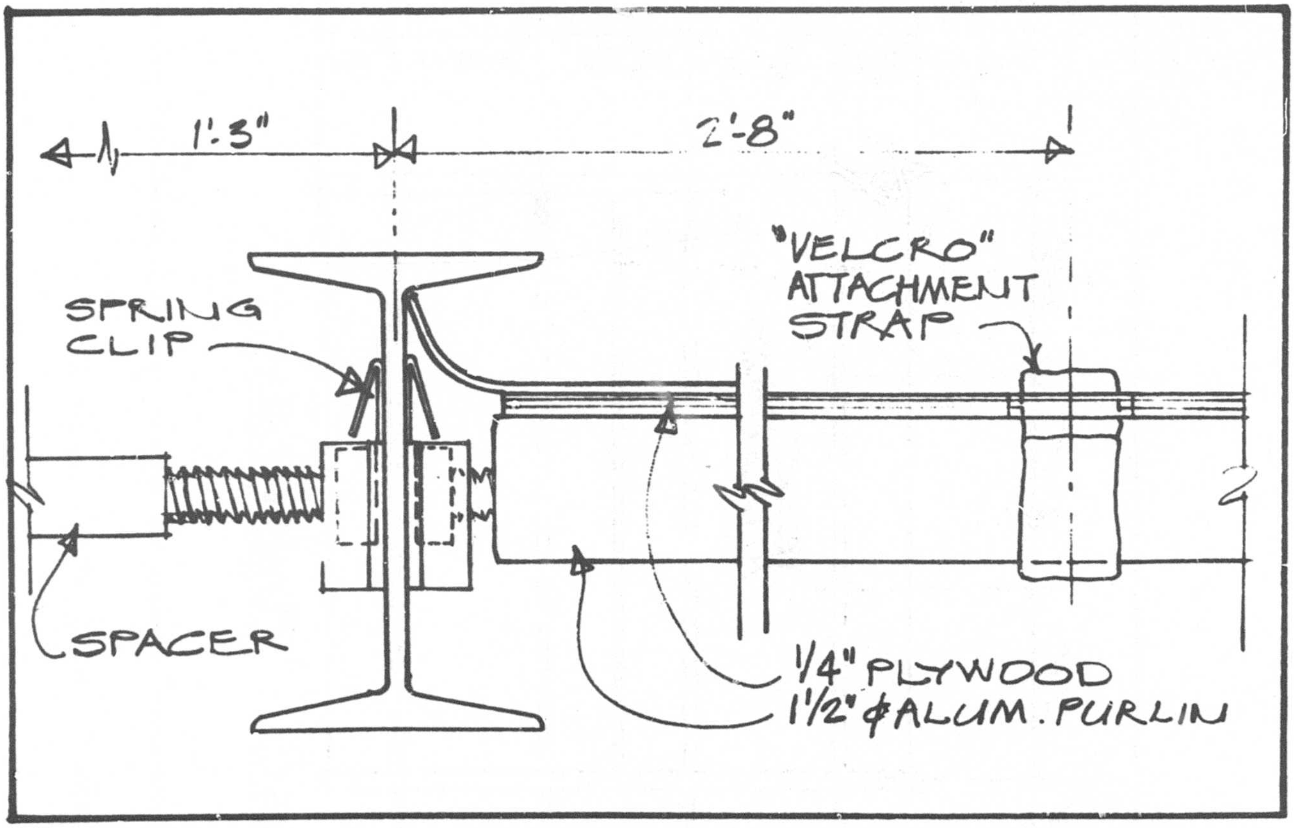


Figure 117. Purlin and Sheathing Detail

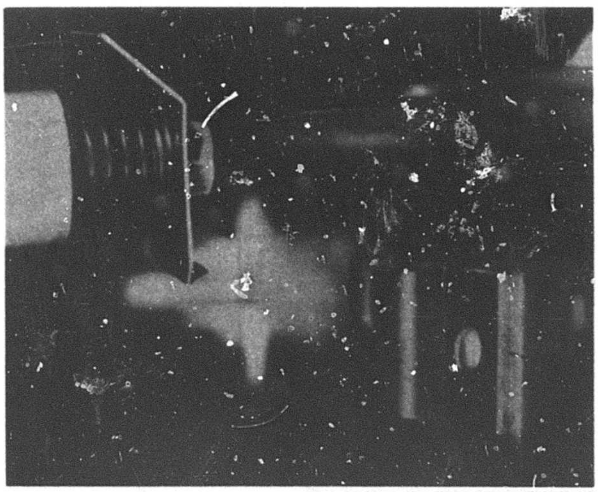


Figure 118. Purlin Detached from Beam

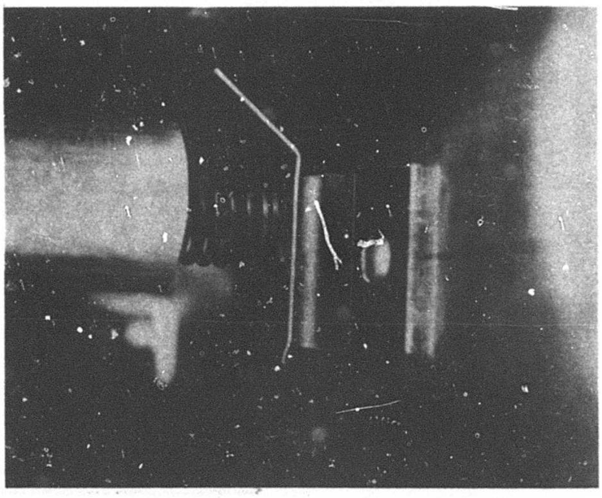


Figure 119. Purlin Attached to Beam

B. TEST ERECTION

The prototype hangar arch was erected at the University of Cincinnati in November, 1967. Four men were able to erect the arch in 45 minutes or three man-hours. Therefore, the structure for an eight arch hangar could be erected in 24 man hours. Adding estimated man hours for laying out base pads, flashing panels and installing end walls results in a possible overall erection time of 75 man hours.

The sequence of erection steps was:

1. Assembly of Erection Gantry

For this test erection, the temporary wooden gantry was used. (Figure 120) A more durable aluminum gantry was fabricated. It could be disassembled for packaging and was delivered with the prototype arch to assist erection for the arch static test.

2. Base Pad Layout

The base pads are laid out and staked down. The base arch beam sections attach to the base pads by passing a bolt through the beam web and two base pad angles. (Figure 121)

3. Attach Panels to Beams

A panel is locked to a beam by inserting an Allen wrench into a panel cam lock and rotating the cam to engage the receptor pin which is mounted on the beam web. (Figure 122)

4. Attachment of Erection Gantry

With two arch beam top hinge pins engaged, the ends of the gantry lifting cables are clamped to the top beam flanges. (Figure 123)

5. Raising the Arch

The portion of the arch previously assembled is raised with a hand winch until the bottom beam hinges engage. (Figure 124) The bottom hinges are pinned, and the gantry lifting clamps are removed.

6. Completed Arch

The above steps are repeated until the arch is completed. (Figure 125) The last two base arch beams are pinned to their base pads and the erection gantry can be moved in place for raising the next hangar arch.

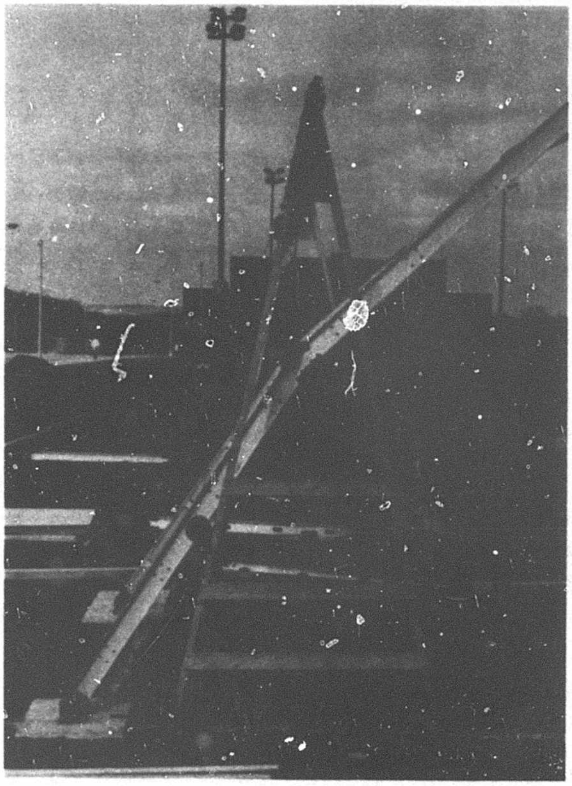


Figure 120. Assembly of Wood Gantry

Figure 121. Base Pad

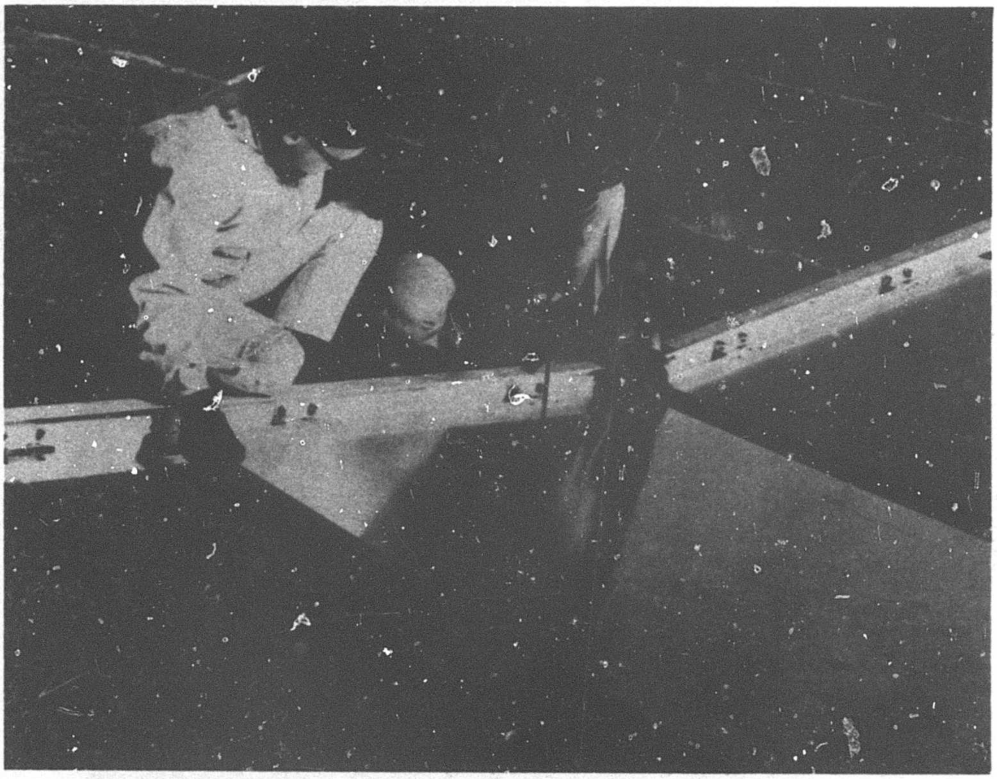


Figure 122. Attaching Panel to Beam

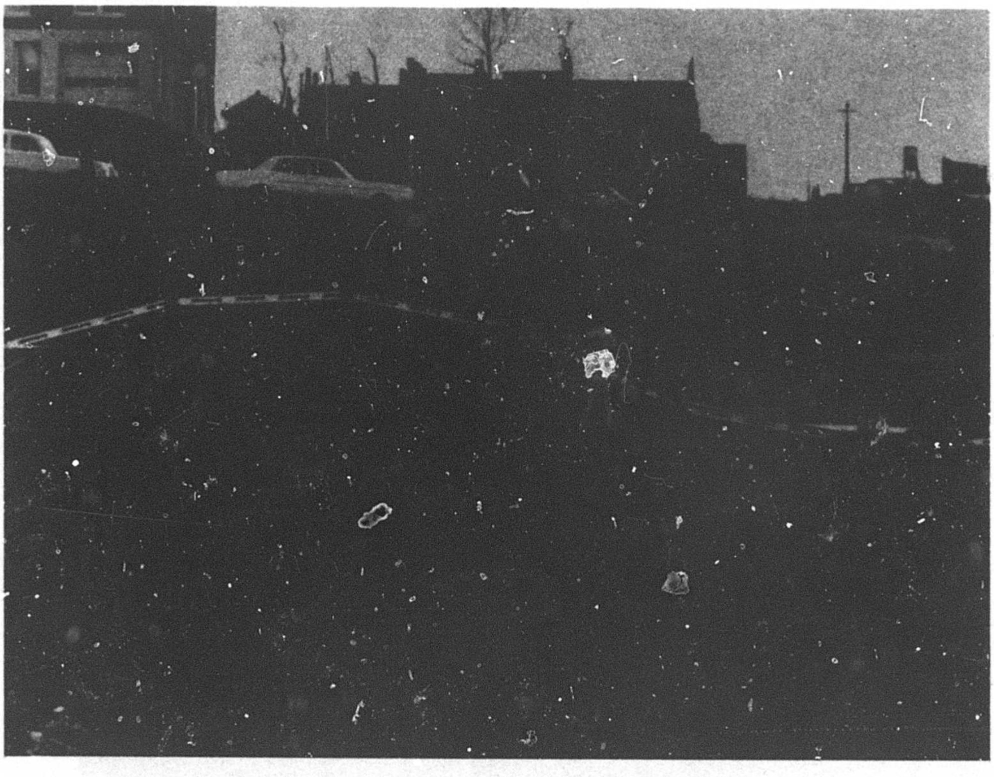


Figure 123. Attaching Gantry to Arch

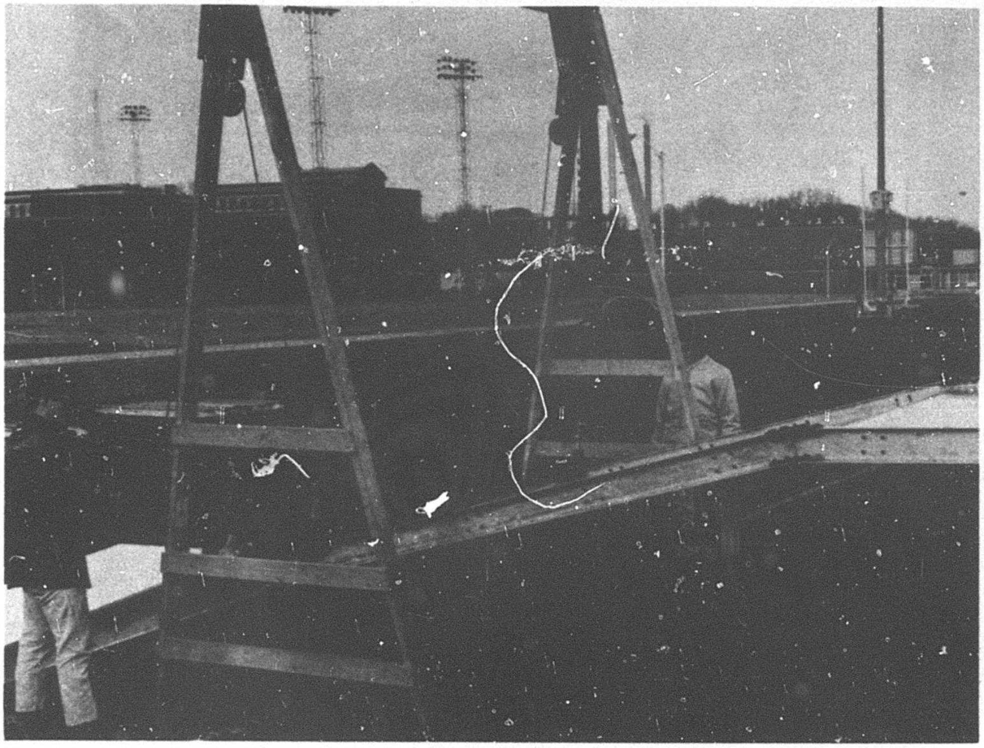


Figure 124. Raising the Arch

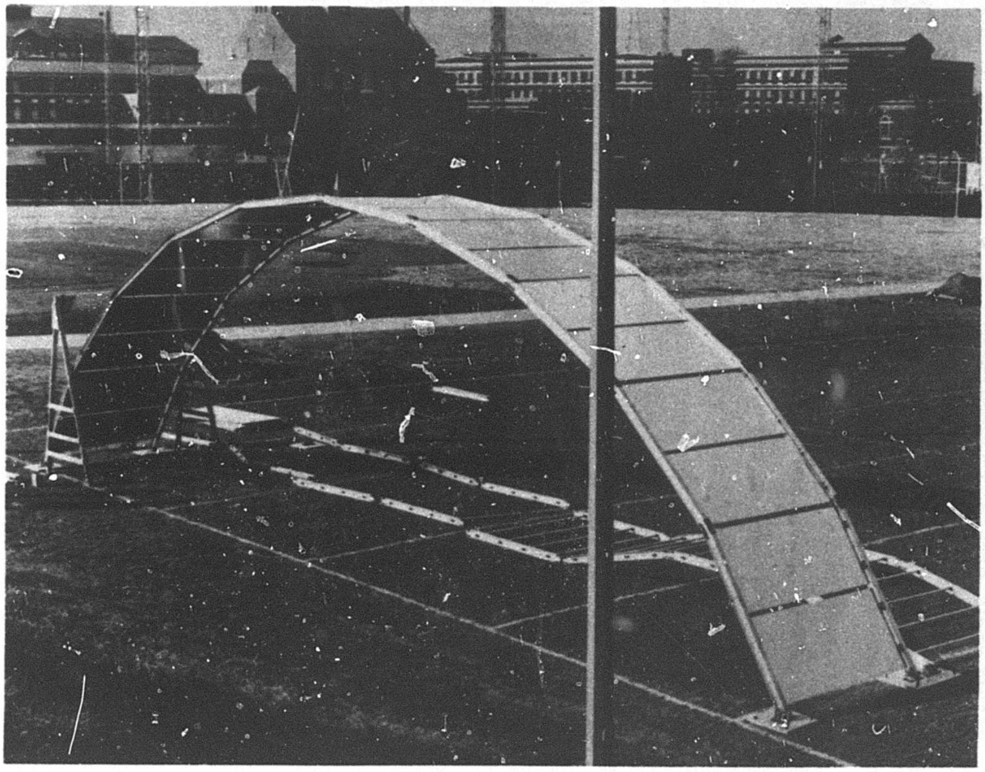


Figure 125. Completed Arch

C. ARCH STRUCTURAL TEST

The prototype beam and panel hangar arch was erected and static tested at Wright-Patterson Air Force Base in the Flight Dynamics Laboratory under supervision of Air Force personnel. (Figure 126)

The loads were applied to the panel cam locks in accordance with Figure 99 and Table II.

The structure was loaded to a 90 mph equivalent loading by means of hydraulic jacks. (Figure 127) This loading, i.e. 0 to 90 mph, was repeated five times over a period of six hours and then it was loaded to destruction. At a 122.4 mph equivalent load, one of the hydraulic jack attachments broke and the loading was stopped. The structure deflected 13" horizontally at its highest point and, as soon as the load was removed, it recovered immediately.

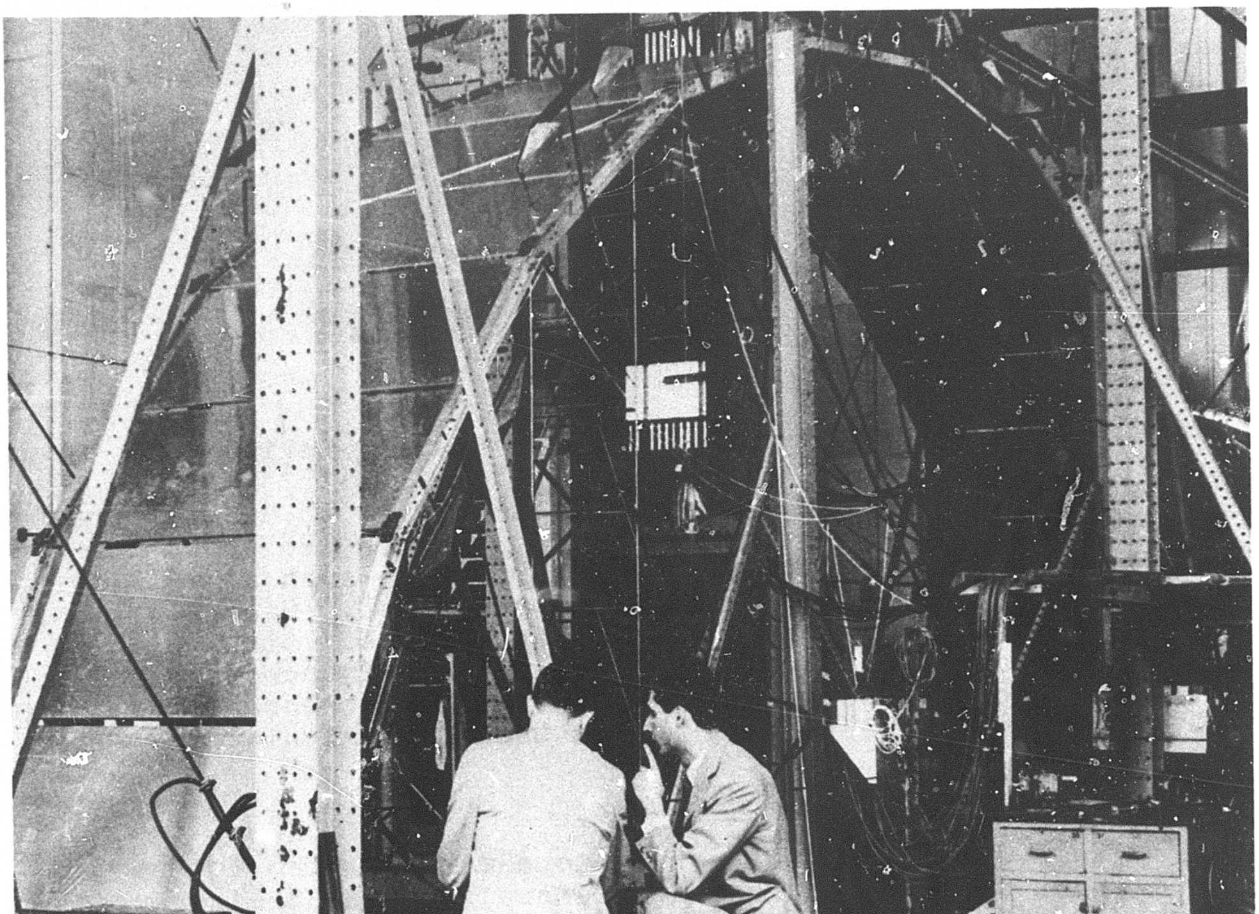


Figure 126. Arch Test

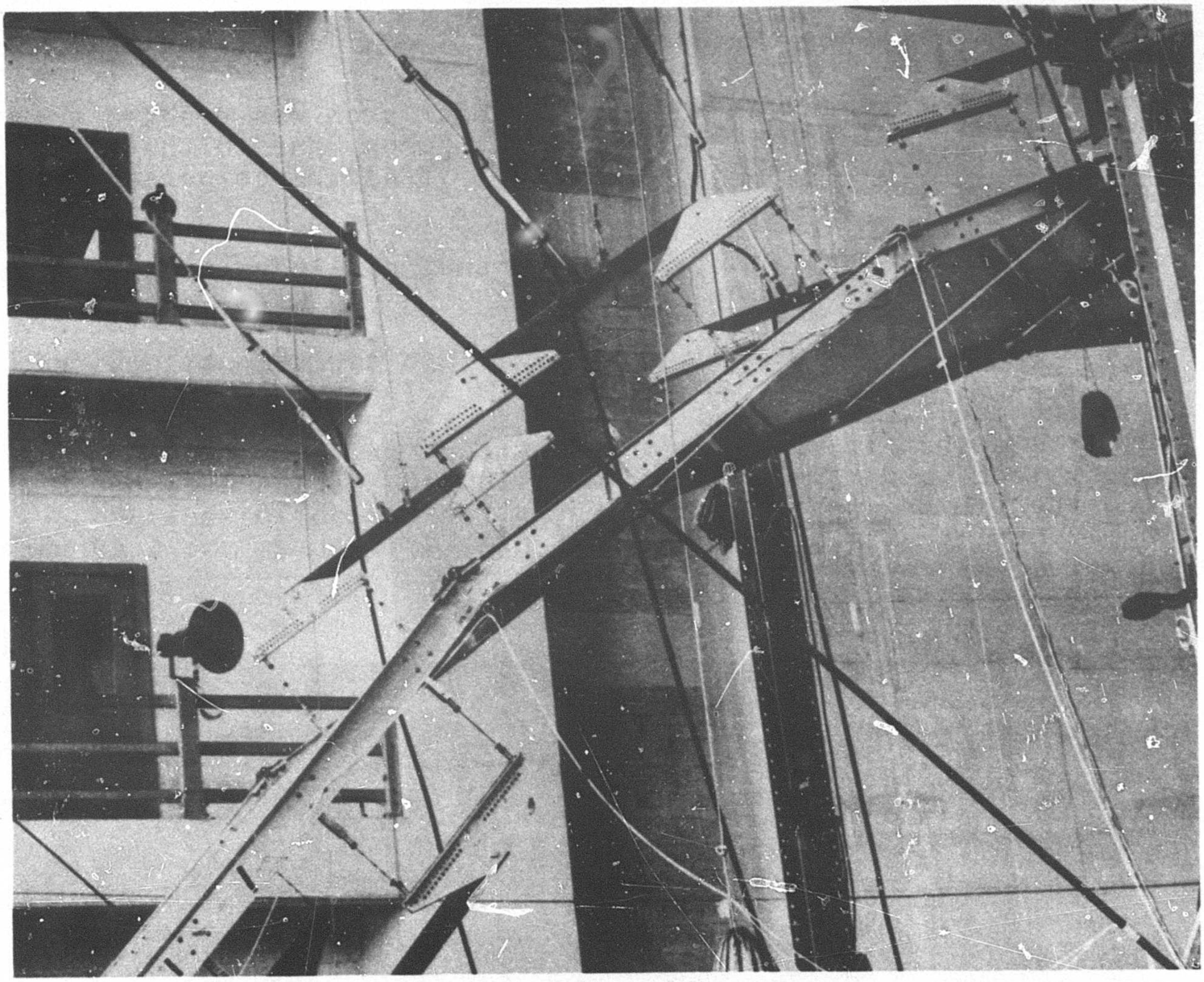


Figure 127. Hydraulic Jack Loading Device

Strain gauges were mounted on all beams to detect stress variations across the two arch ribs. Figure 128 shows the theoretical bending moment variation across the arch as well as the experimental results obtained from this test. Generally, the actual induced moments are less than the theoretical. One reason was that some frictional restraint was induced at the pinned ends. Secondly, actual dead weight of the structure was slightly lighter than the estimated weight used for calculation.

D. PANEL STRUCTURAL TESTS

Four basic types of panels were manufactured for use on the first full size hangar and General Purpose Shelter prototypes. (Figure 129) These four types all have .032" aluminum skins and vary in core materials and method of attaching skins. Specimens 1 through 3 have Styrofoam cores, and skins are riveted to perimeter edge close-out extrusions. Specimens 4 and 5 have Styrofoam cores and no edge rivets. Specimens 6 and 7 have balsa wood cores. Specimens 8 and 9 have paper

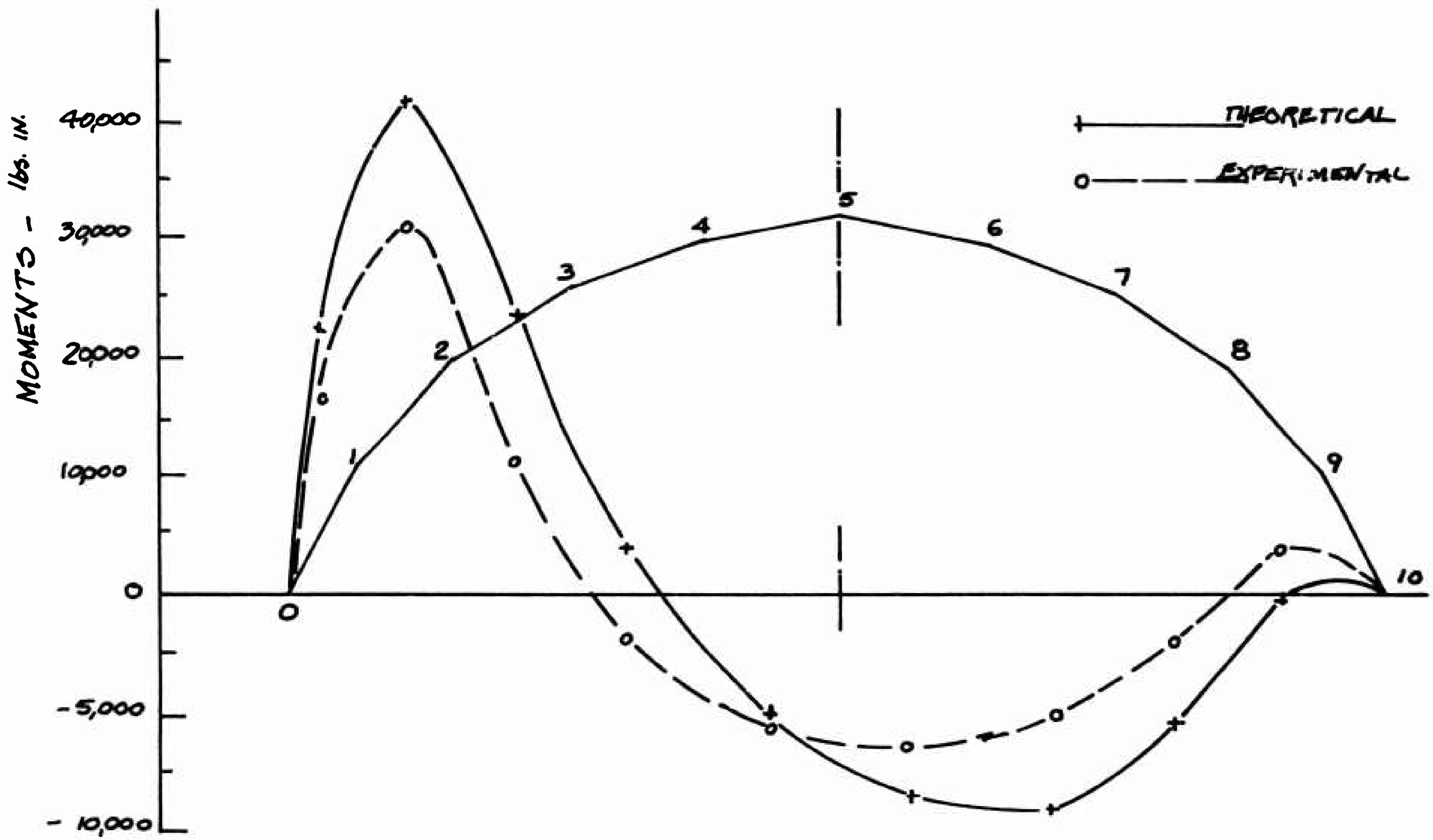


Figure 128. Bending Moments Across Arch Rib

PANEL TYPE	TYPE A	TYPE B	TYPE C	TYPE D
Styrofoam Core	●	●		
Balsa Wood Core			●	
Paper Honeycomb Core				●
Skins Riveted to Close-out Extrusions	●			
Skins Bonded With P.P.G. #426 Adhesive	●	●	●	
Skins Bonded With Epoxy Adhesive				●

Figure 129. Panel Descriptions

honeycomb cores. Six panels each (specs 3, 5, 7 and 9) of the four basic types were fabricated for test analysis.

Static and dynamic test results of three separate tests performed on each panel type are shown in Figure 130. The panels were cam-locked into "I" beams for this testing, and beams were supported as indicated on the diagram in Figure 130. The results presented are the average of the three separate tests. After static testing, the same panel type underwent dynamic loading of 25 lbs/sq ft. They were cycled 10,000 times (8 sec/cycle) and deflections were measured. It can be seen that cycled testing has a slight effect on the Styrofoam panels, but it has no effect on the paper honeycomb and balsa wood panels. Also it can be noted that riveting of panel skins to edge extrusions had no effect on panel performance.

Heat tests were also performed on these panels. They were heated individually on one side (Figure 131) to a temperature of 180° for five hours and then cycled (110° to 180° F) in one minute intervals for one hour. After this, the panel underwent static testing described earlier to investigate any caused defect. In all four panel types there were no visible defects, and test result load/deflection curves were practically identical to those of non-heated panels. No visual defects could be seen when 1' x 1' sections were cut from the panels that

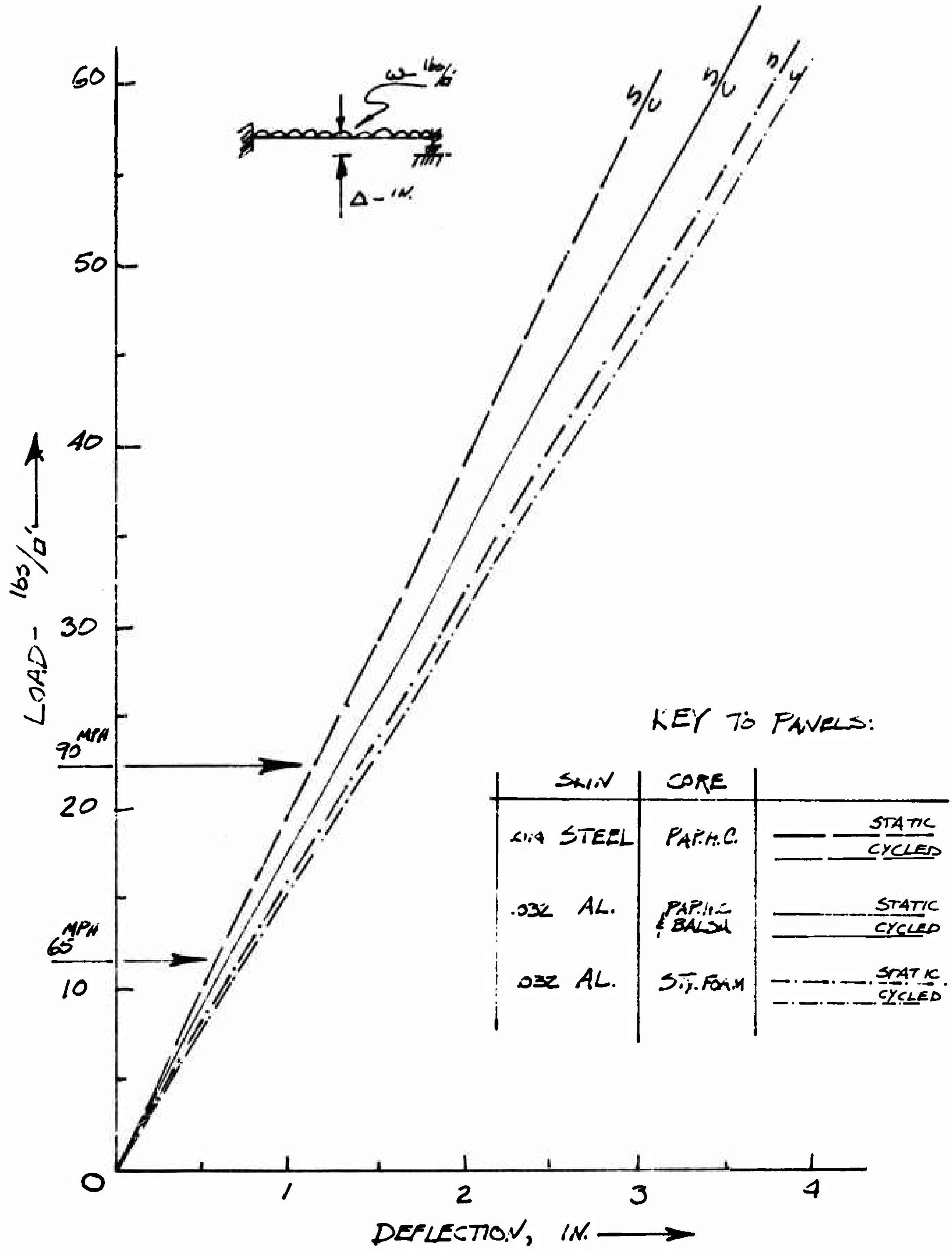


Figure 130. Load-Deflection Relationship for Test Panels

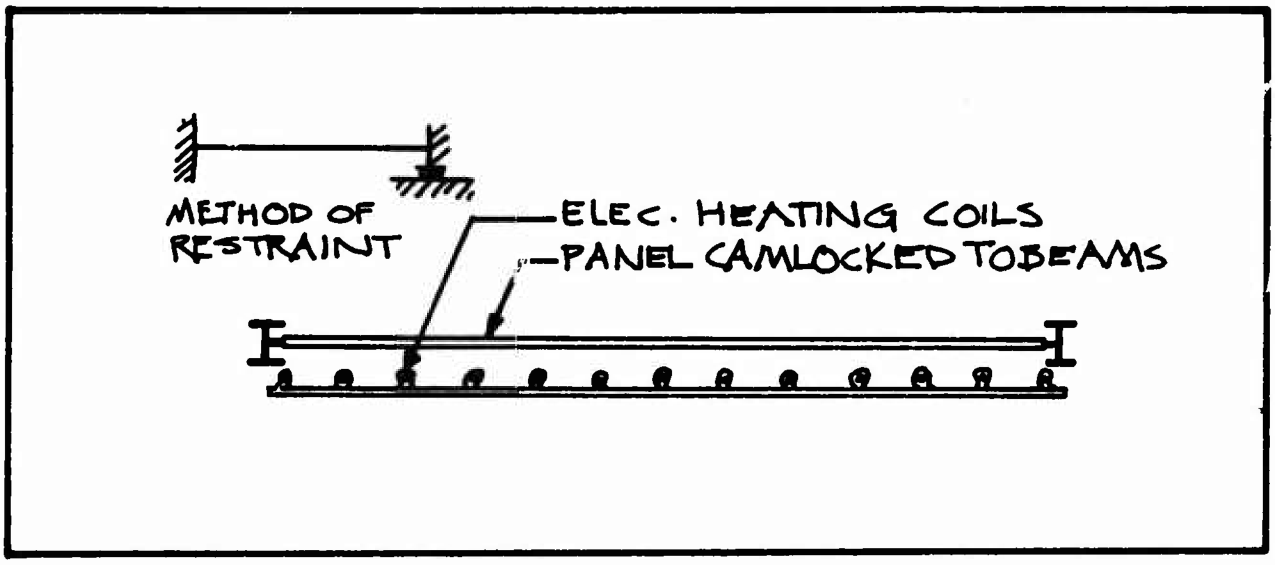


Figure 131. Panel Heat Test

had been tested. However when these 1' x 1' sections were placed into an oven and heated for 1-1/2 hours at 185° F, the Styrofoam core sample deformed and the core expanded whereas the paper honeycomb and balsa wood samples remained intact. The Styrofoam cores exhibit better resistance to heat when fully enclosed in a panel with edge extrusions and are generally acceptable and by far the least expensive. However, the paper honeycomb panels, which are lighter and less expensive than the balsa wood panels, exhibit the best potential from the standpoints of strength and durability.

VII

FIRST PROTOTYPES

The first Hangar and General Purpose Shelter full size prototypes were delivered to Wright-Patterson Air Force Base in August of 1968. These shelters were erected before being shipped out for field test. The Hangar was test erected and monitored at Eglin Air Force Base in Florida, and the General Purpose Shelter was test erected and monitored at Howard Air Force Base in the Panama Canal Zone.

A. FIRST HANGAR PROTOTYPE

Fabrication of this shelter was performed by subcontractors representing the various trades involved. The metal components were fabricated by Newman Brothers, Inc., Cincinnati, Ohio. The Styrofoam and balsa wood sandwich panels were fabricated by the Stolle Corporation, Sidney, Ohio. The paper honeycomb sandwich panels were fabricated by Wickes Industries Inc., Los Angeles, California. (See description of different panels in Figure 129.) The fabric components were fabricated by Hoosier Tarpaulin and Canvas Goods Company, Inc., Indianapolis, Indiana. The electrical system was manufactured by Kalsey Electric Company, Cincinnati, Ohio.

Each Hangar component is described in the following paragraphs in terms of its function in the sequence of erection.

1. Base Pad Layout and Anchoring

A Corner base pad is staked down and a base pad locating cable is attached to it. (Figure 132)

Intermediate double base pads are located with markers which are on the locating cable device. (Figure 133)

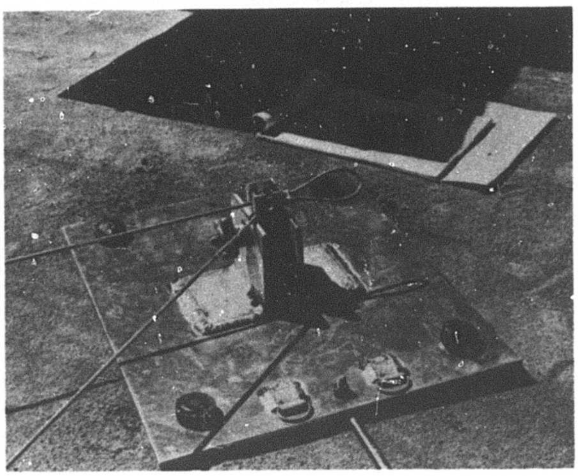


Figure 132. Corner Base Pad with Locating Cable.

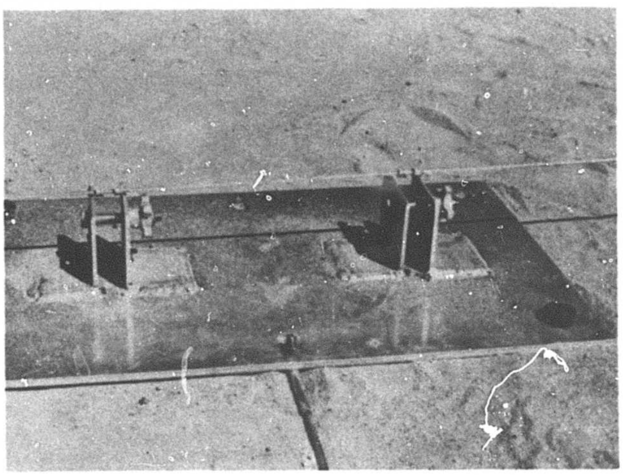


Figure 133. Intermediate Base Pad with Locating Cable.

The cable locating device is triangular, thereby making it possible to lay out base pads on both sides of the shelter and assuring that the shelter end walls are square with the side walls. End wall column base pads are located with the same cable device and staked down. (Figure 134) Ground cables are attached to base pads on opposite sides of the shelter to prevent the shelter arches from spreading. (Figure 135) Note that the Arch Beam sections are distributed next to base pads for easy accessability during arch erection.

A leveling device is provided for insuring that the base pads are within the allowable level tolerances. (Figure 136) This device is clamped to a standard arch beam which is placed from base pad to base pad down each side of the shelter. (Figure 137) Relative adjustments are made to insure that the bubble in the spirit level remains within the limits marked on the glass tube.

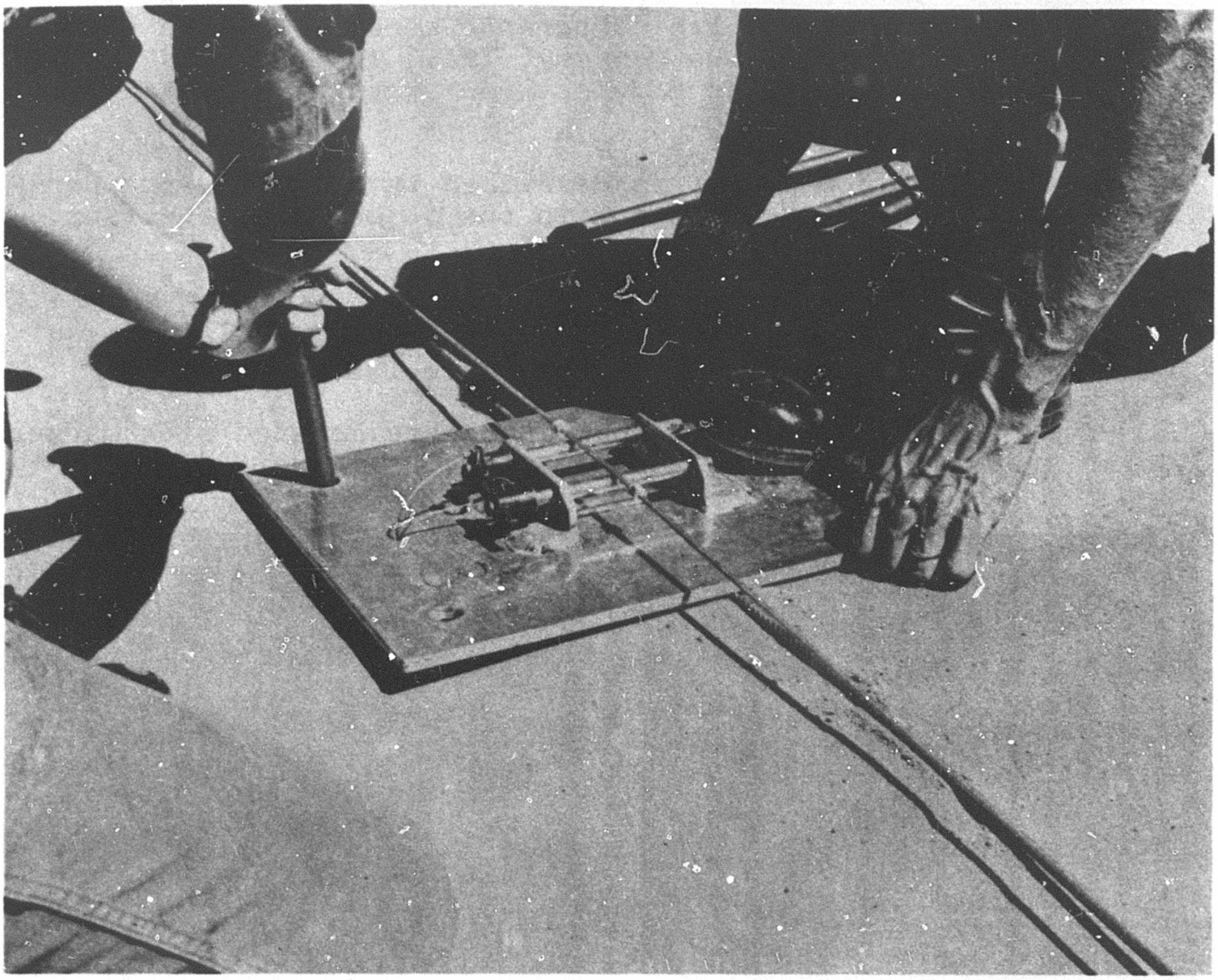


Figure 134. Column Base Pad with Locating Cable

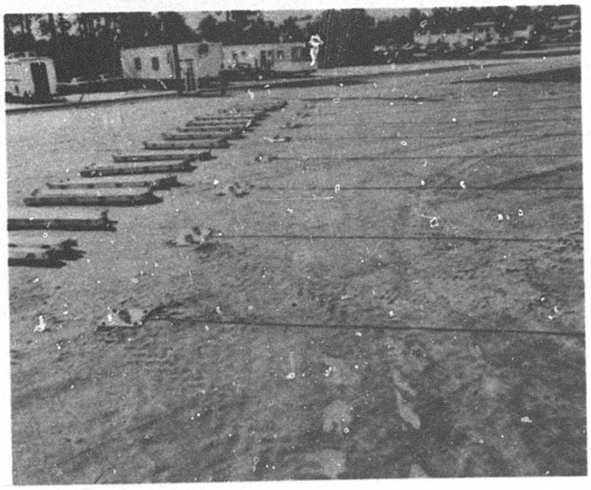


Figure 135. Base Pads with Ground Cables

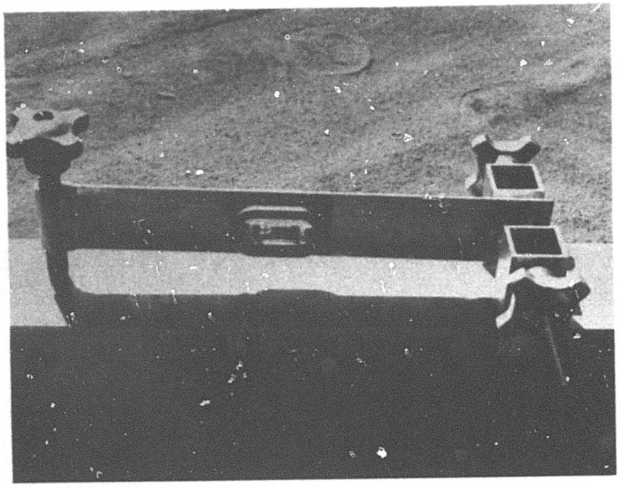


Figure 136. Leveling Device

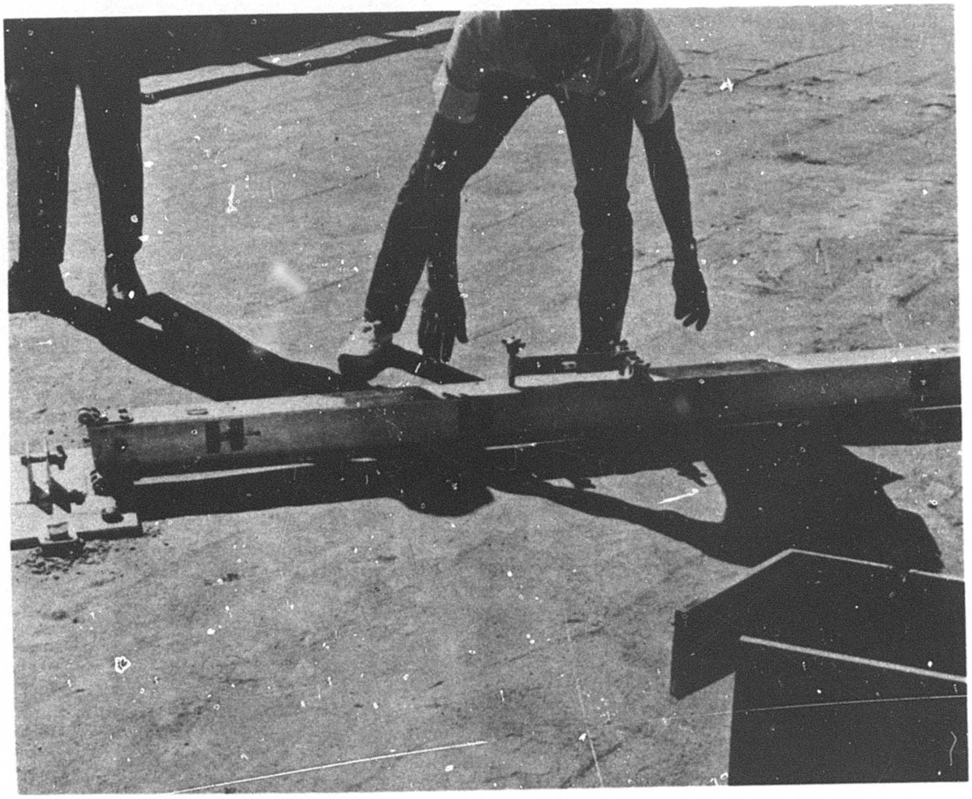


Figure 137. Leveling Device on Arch Beam

2. <u>Erection Gantry Assembly</u>

For shipment, the erection gantry breaks down into four parts. (Figure 138)

Two side "A"-frame parts are locked together for each side of the gantry. (Figure 139)

The top horizontal truss members are folded out and pinned together. (Figure 140)

The gantry is tipped up into a vertical position (Figure 141) and the hand winch is attached. (Figure 142)

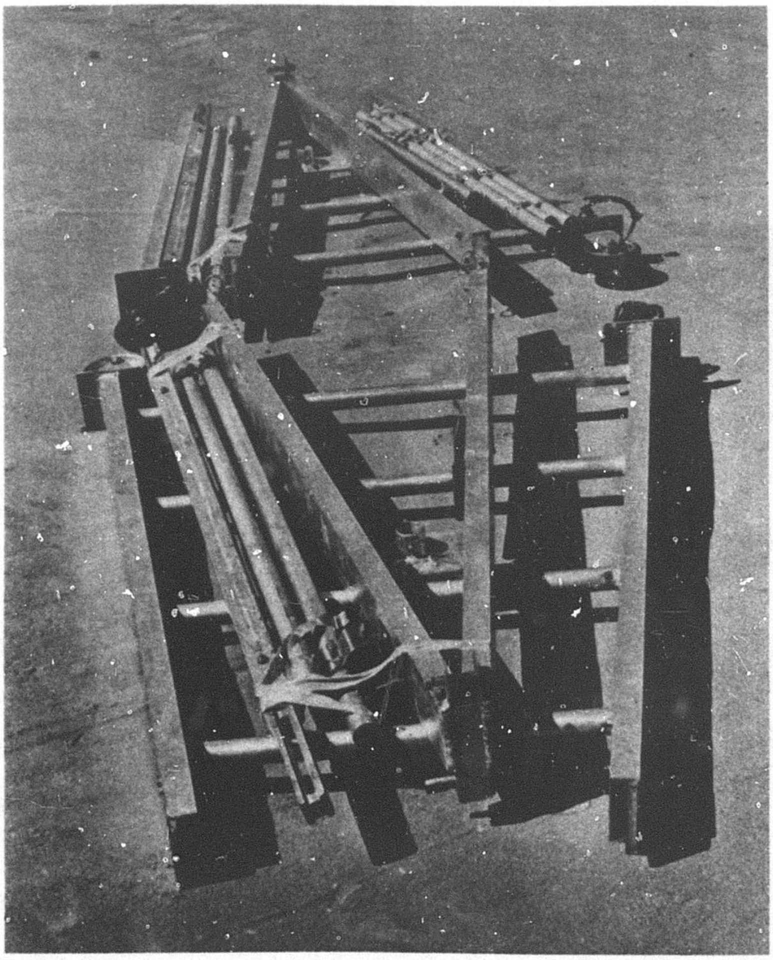


Figure 138. Disassembled Erection Gantry

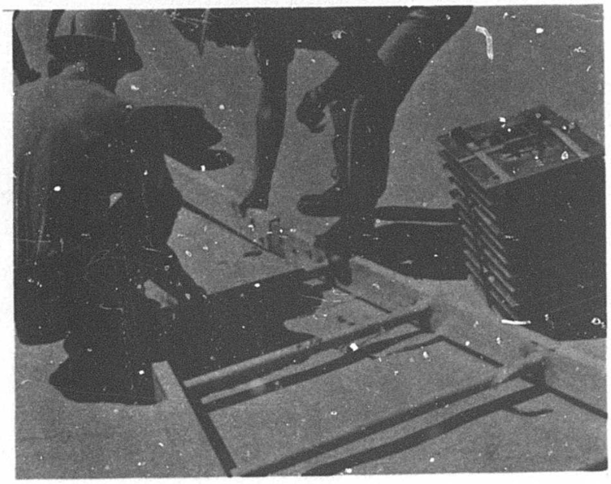


Figure 139. Assembly of Side "A" Frame

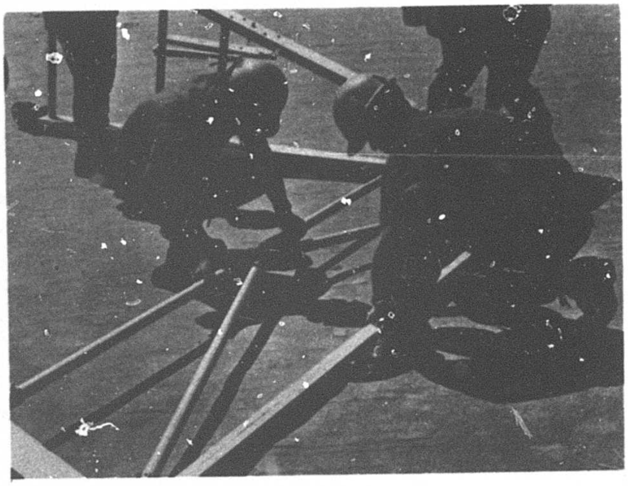


Figure 140. Assembly of Top Truss

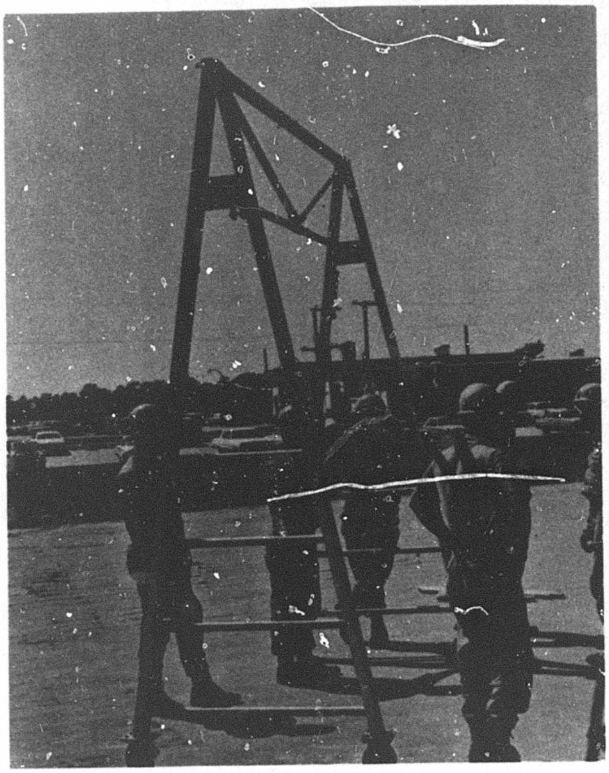


Figure 141. Gantry in Vertical Position

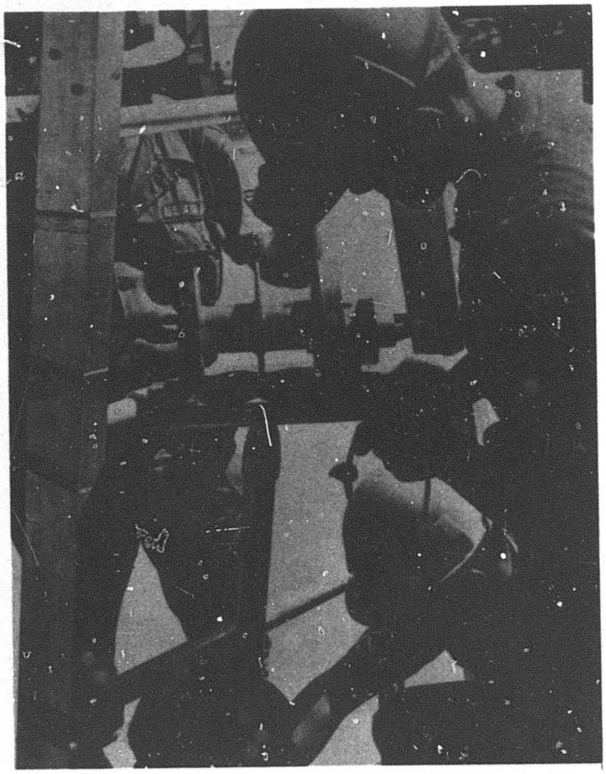


Figure 142. Attachment of Hand Winch

3. Arch Erection

The arch beam section used on the prototype test arch (Figure 102) was changed to a 5" x 3-1/2" aluminum section which weighed 3.69 lb/ft. This is slightly heavier but was worth the increased weight because the faces of the beam flanges were parallel so that the beveled washers could be omitted.

For an eight-arch hangar the six intermediate arches are erected first. Then the end arches are raised with the end walls.

First the base arch beams are pinned to the base pads. (Figure 143)

Next the panels are cam locked to the beams. (Figure 144)

The next pair of arch beams are attached by pinning the top hinges and the second double panel assembly is cam locked to these beams. (Figure 145)

The beams are raised by hand until the bottom hinges engage and are pinned. (Figure 146)

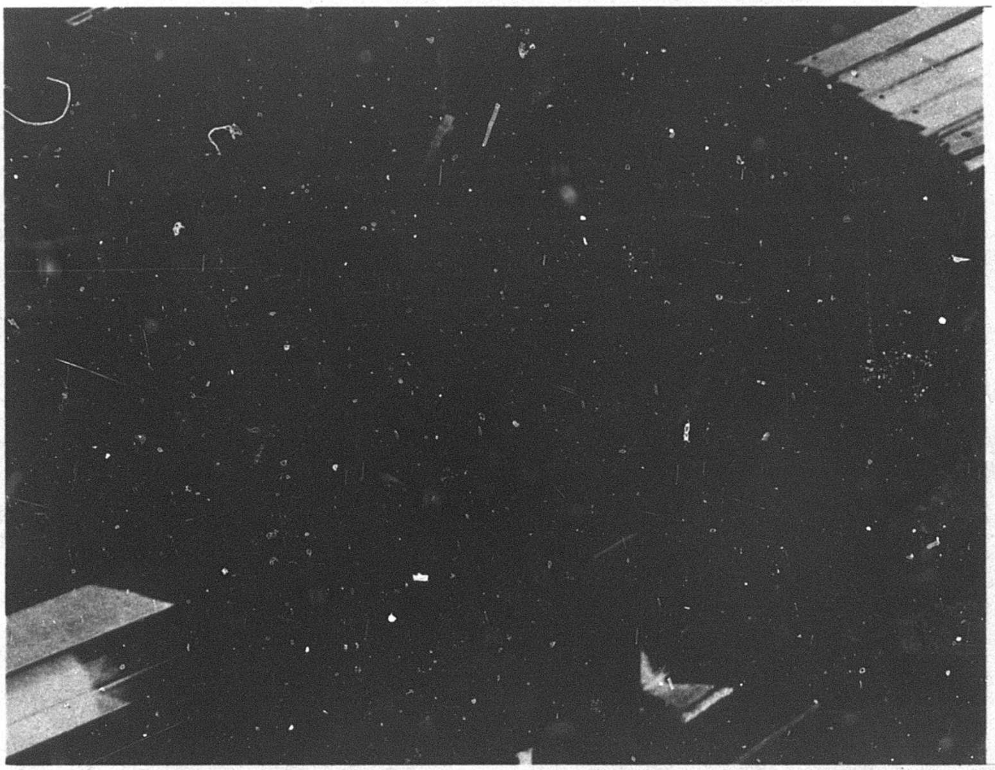


Figure 143. Base Beam Pinned to Base Pad

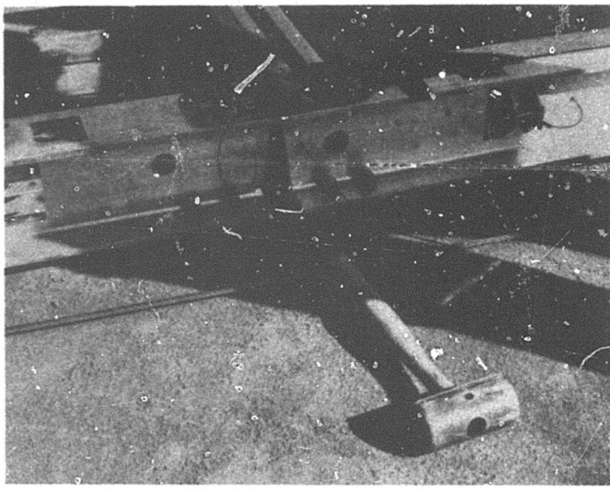


Figure 145. Top Pin Inserted

Figure 144. Panels Camlocked to Beams

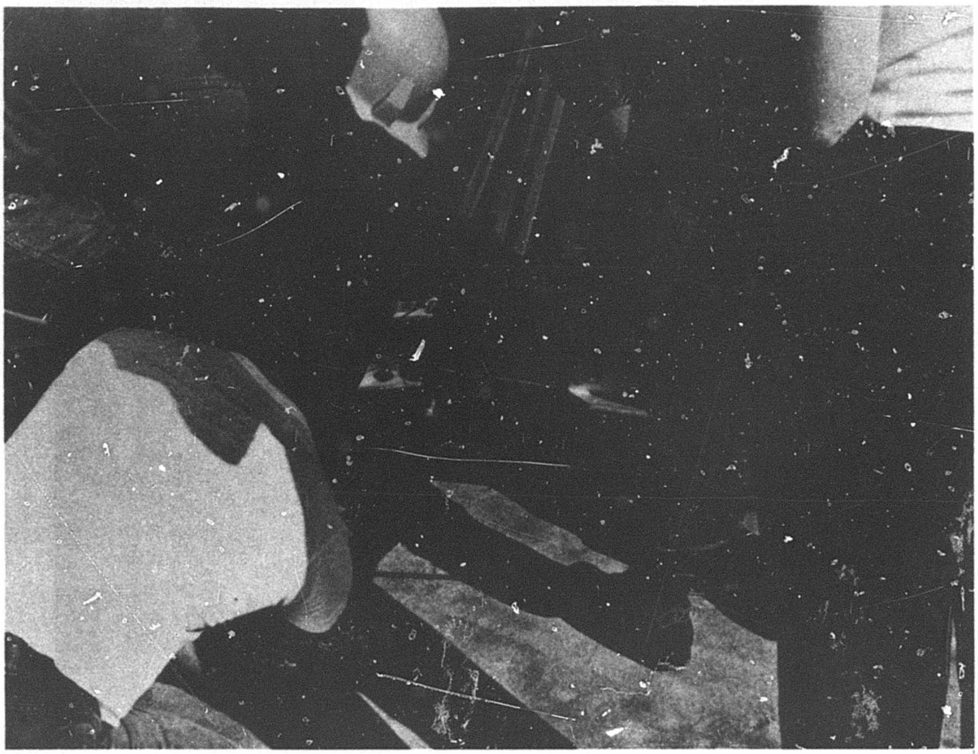


Figure 146. Bottom Pin Inserted

Four beam-panel modules can be assembled by hand. Then the erection gantry is rolled into place and the lifting cables are clamped to the arch beams for raising the arch with the hand winch. (Figure 147) (Note: the panel to panel flashing is being closed after the bottom hinges are engaged).

The panel to panel flashing on the first prototypes was sealed by pressing together two 1" wide strips of Velcro tape separated by a rubber gasket. (Figure 148)

At the ridge of the hangar the panels must change direction for watershed. A special ridge flashing is required as shown in Figure 149.

After ten beam-panel modules are assembled, the arch is "kicked-out" at the base on one side due to deflection under its own weight. (Figure 150)

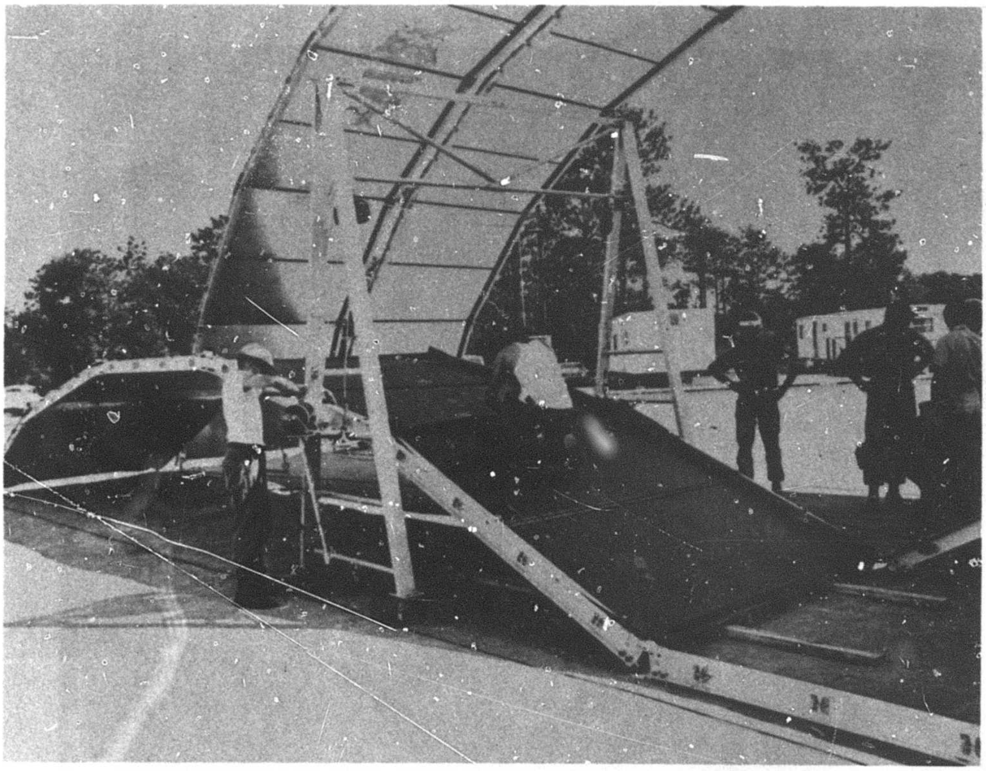


Figure 147. Erection Gantry in Use

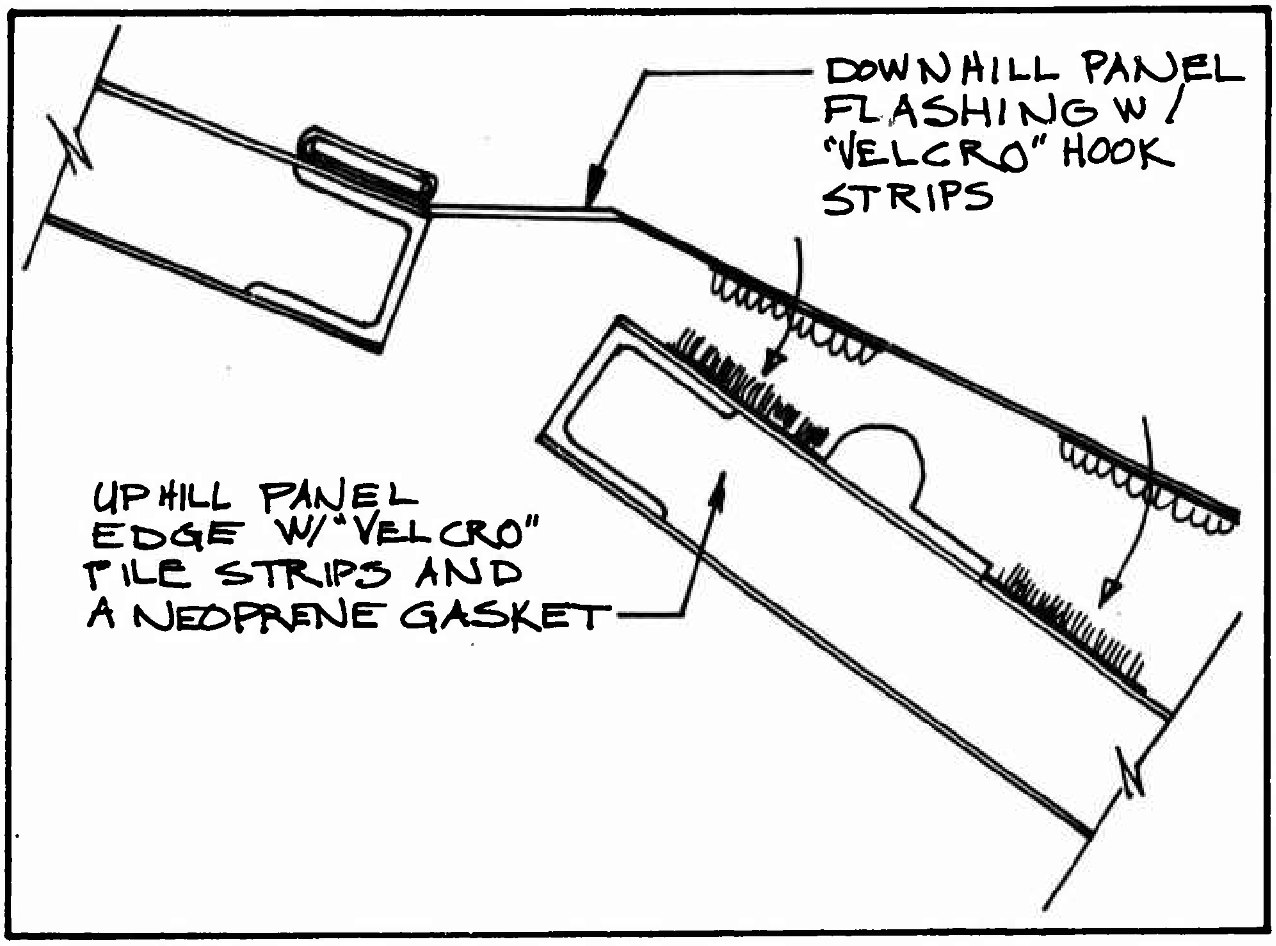


Figure 148. Panel to Panel Flashing

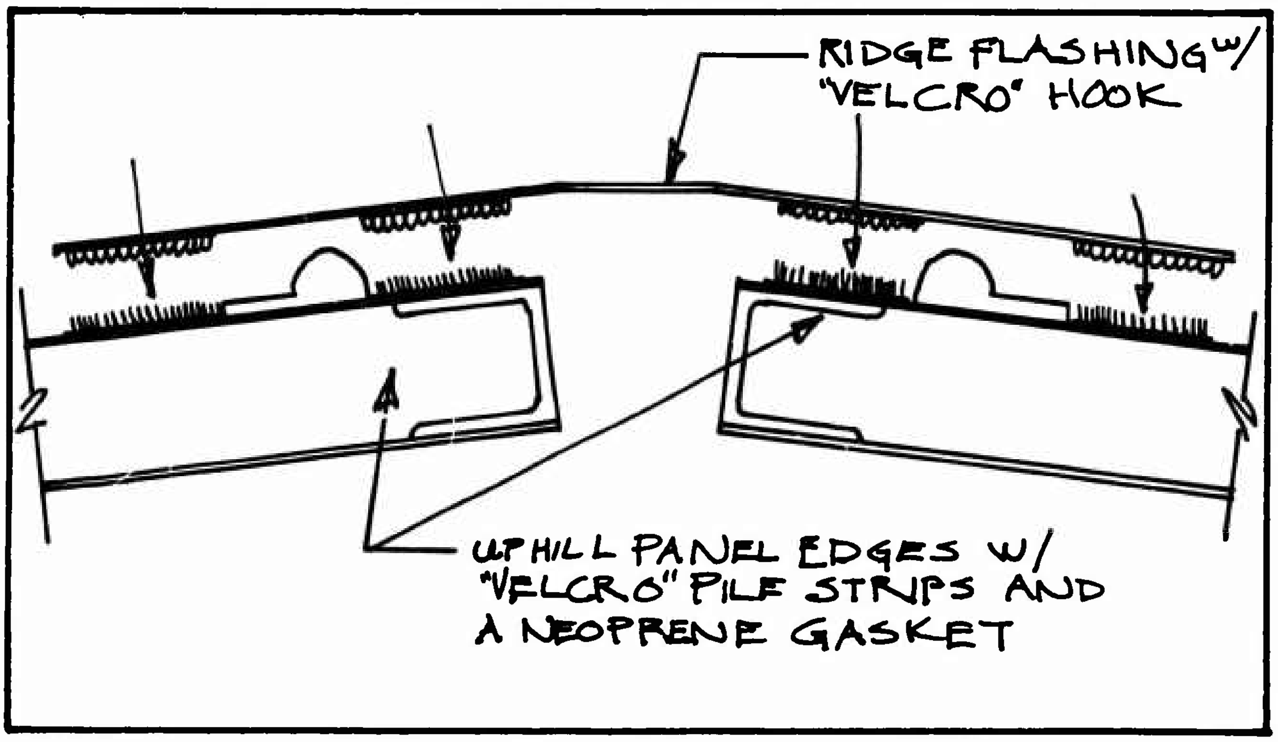


Figure 149. Ridge Flashing

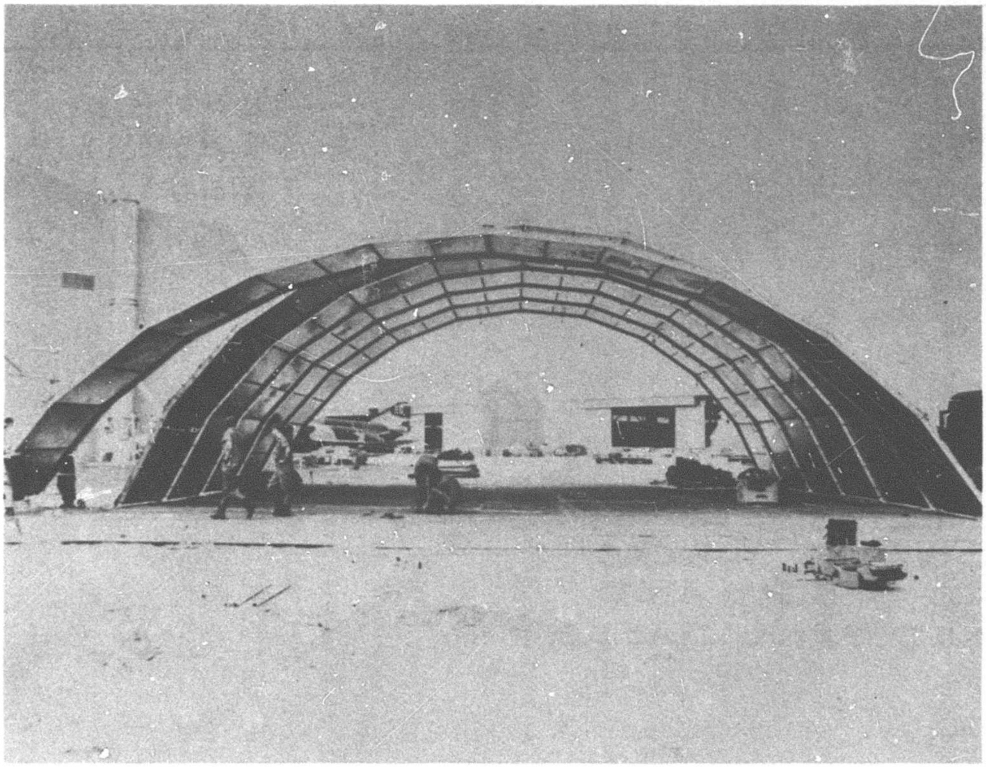


Figure 150. Arch in "Kicked-Out" Position

The arch is pulled in with a come-along and cable yoke assembly (Figure 151), and the free end beams are pinned to their respective base pads.

When two adjacent arches are erected they are locked together by swinging the spacers out from one beam web, loosening the hand knob to slide spacer out to the right length, and pinning the spacer to corresponding fittings on the adjacent beams (Figure 152). Then the hand knob is tightened with a tool provided in the tool kit. (Figure 153)

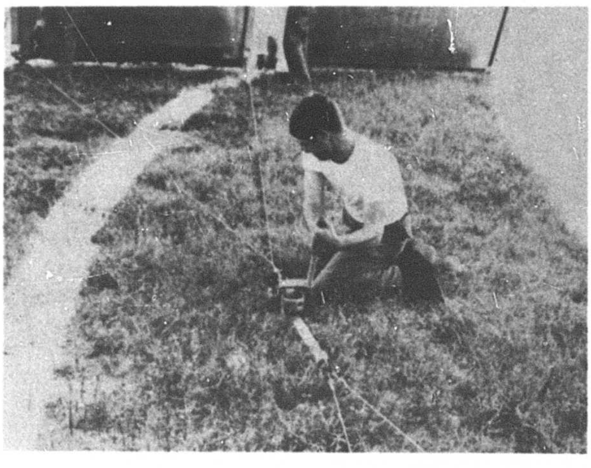


Figure 151. Come-Along in Use

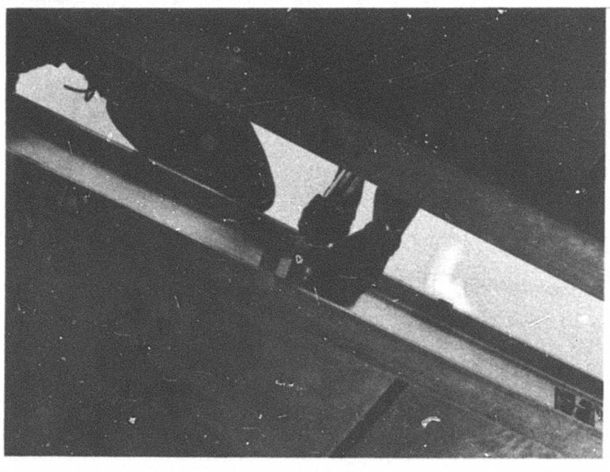


Figure 152. Spacer Pinned to Arch Beam

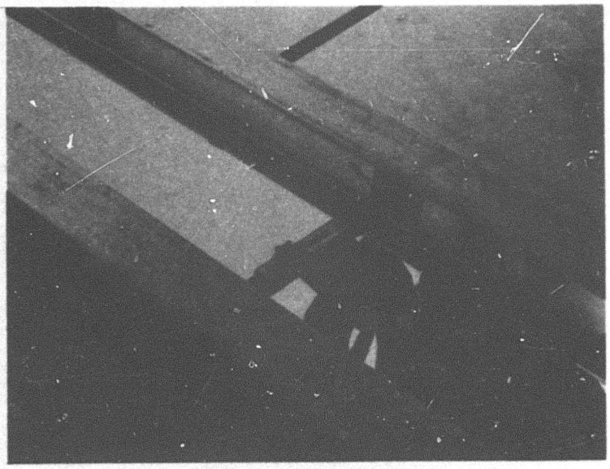


Figure 153. Locking Spacer Handknob

4. Openable Fabric End Wall

The openable fabric end wall is unfolded (Figure 154) and snapped to the end arch as it is being raised. (Figure 155) End wall flashing is clipped to the arch beam. (Fig. 156)

Two pivoting columns are located with the column-locating device and clamped to the arch beams. (Figure 157)

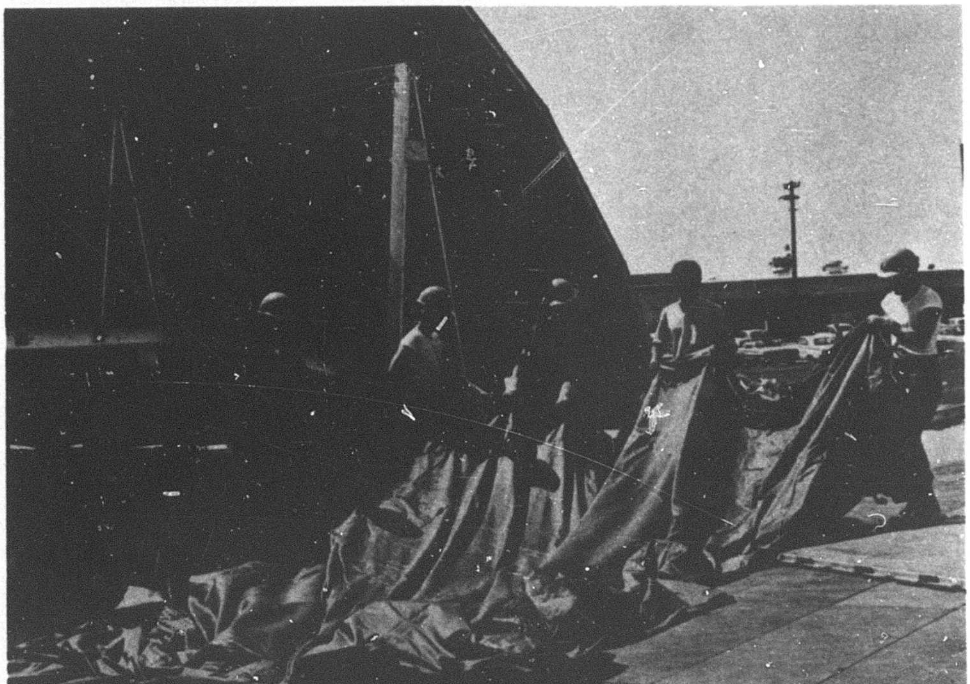


Figure 154. Unfolding Fabric End Wall

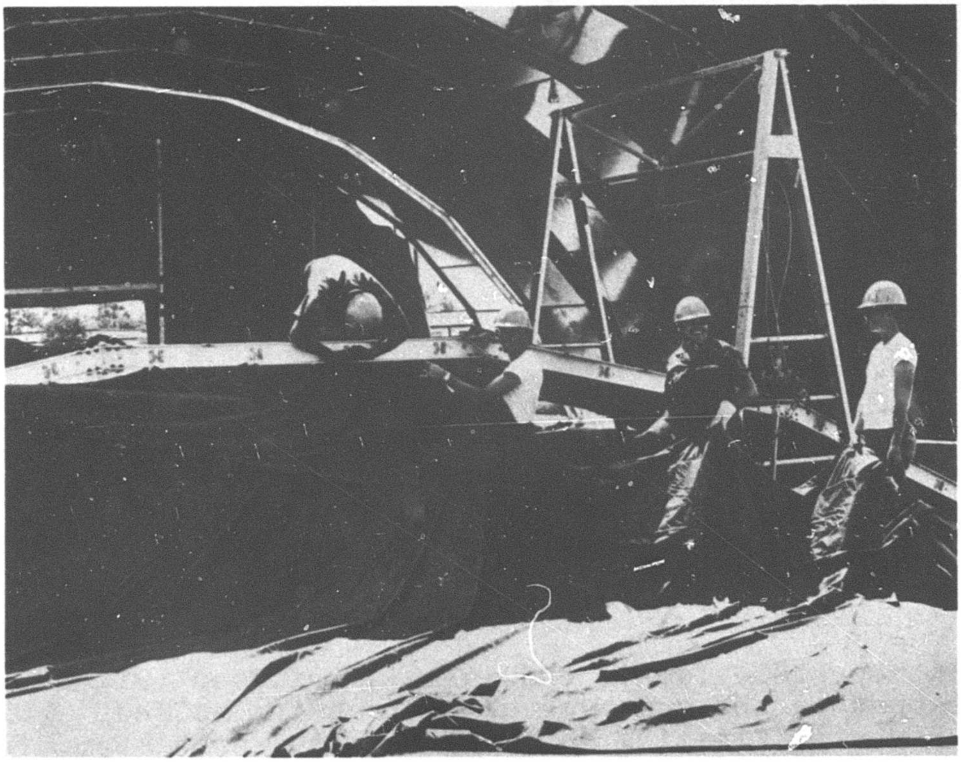


Figure 155. End Wall Snapped to Arch Beams

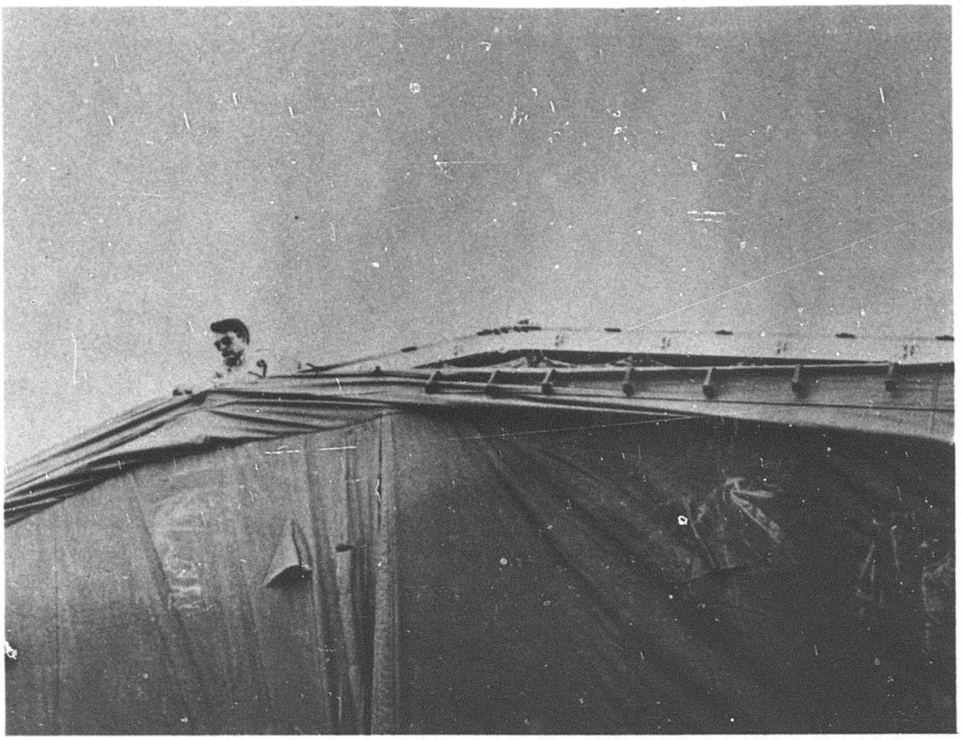


Figure 156. End Wall Flashing Clipped to Arch Beams

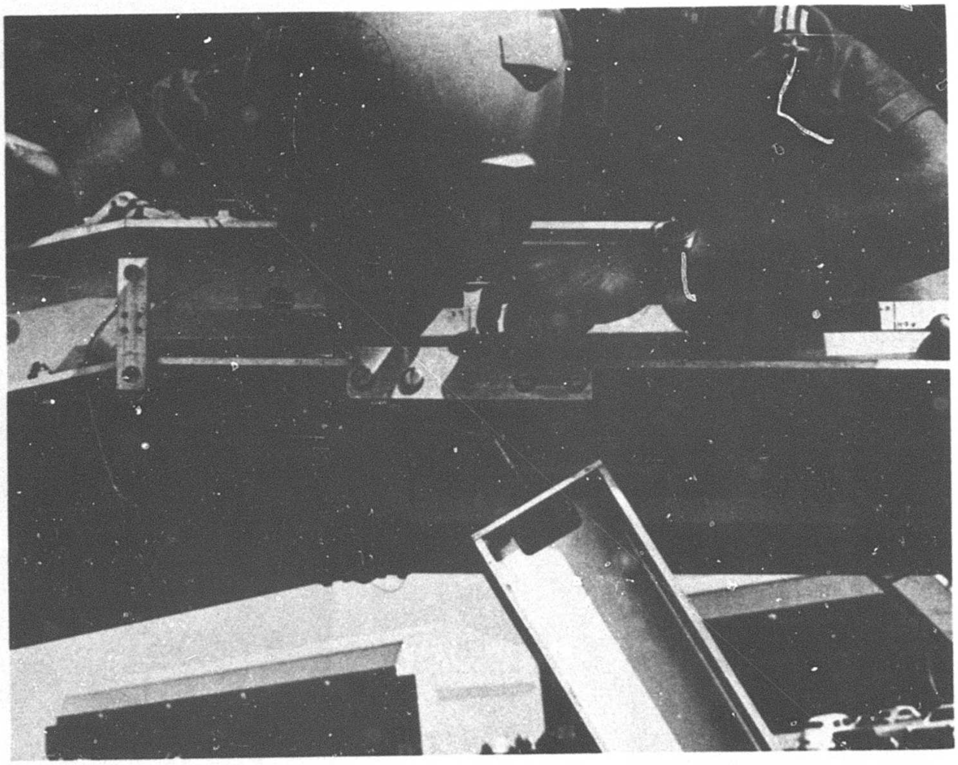


Figure 157. Column Attachment to Arch Beam

The columns are pulled up (Figure No. 158) with a cable which passes through a pulley clamped to an arch rib beam. (Figure No. 159)

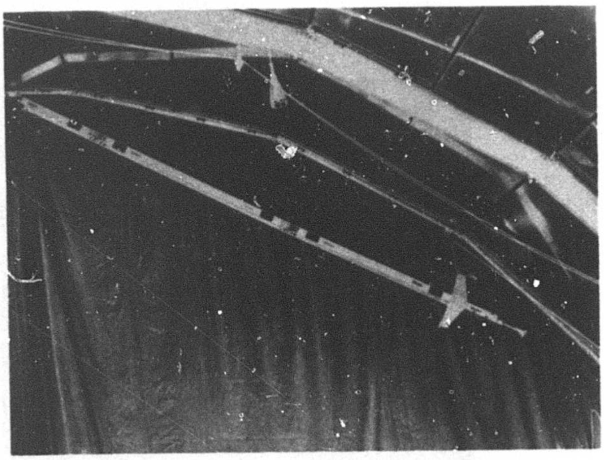


Figure 158. Column in Raised Position

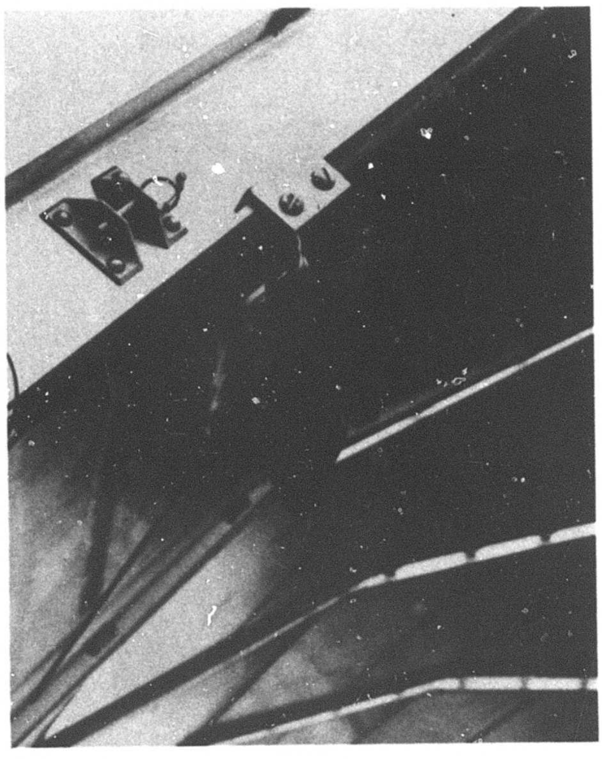


Figure 159. Pulley Attached to Arch Beam

The pivoting columns prevent the end wall arch structure from experiencing excessive deformation during high wind loading on the end wall. Heavy reinforcing straps in the end wall fabric attach to the top (Figure 160) and the bottom (Figure 161) of these columns.

On each side of the openable fabric end wall a column, which receives a triangle shaped personnel door, is clamped to the arch beams. (Figures 162 and 163)

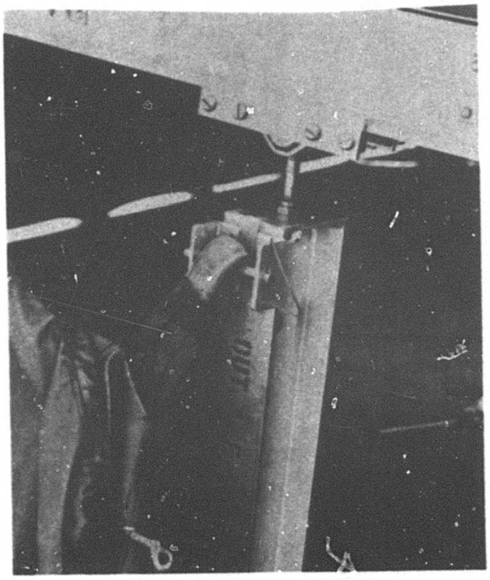


Figure 160. Reinforcing Strap at Top of Column

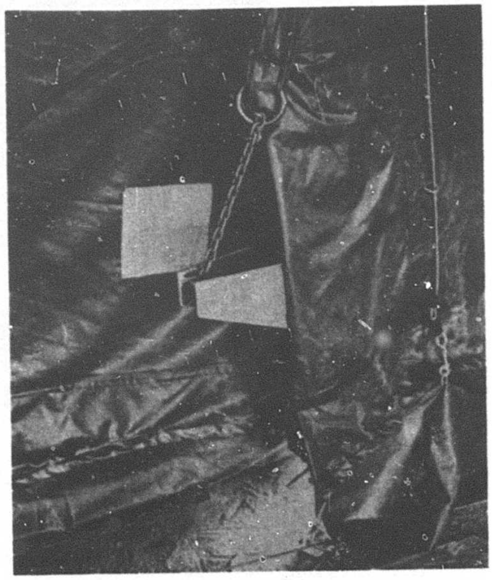


Figure 161. Strap Attachment to Bottom of Column

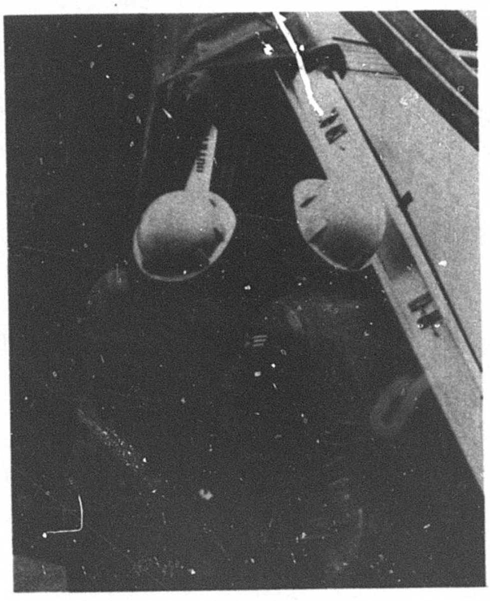


Figure 162. Personnel Door Column

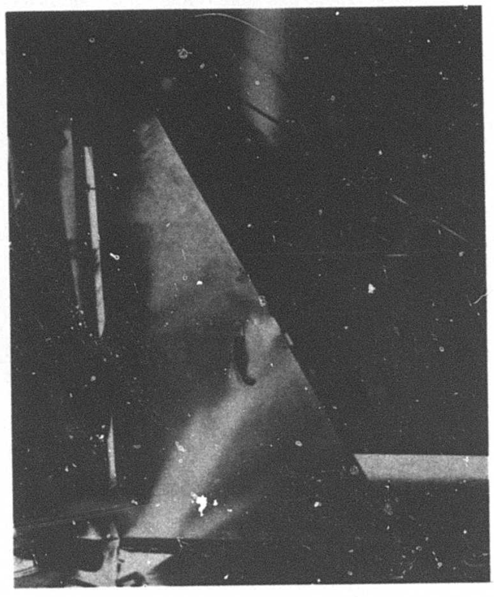


Figure 163. Personnel Door

Special hardware designed for these doors is shown in Figure 164 (outside view) and Figure 165 (inside view).

When all eight arches are erected, the hand winch is removed from the erection gantry and attached to the spacers nearest the end wall. (Figure 166) It is then used for raising the fabric end wall.

Figure 164. Door Hardware Outside View

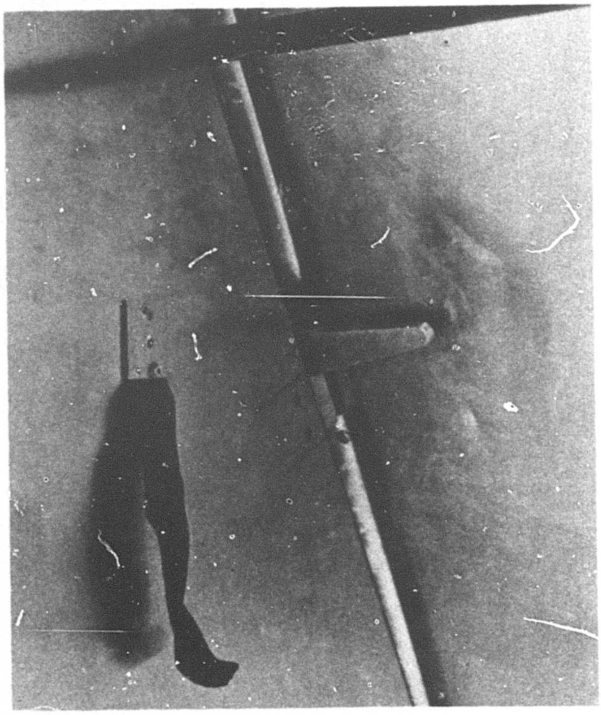


Figure 165. Door Hardware Inside View

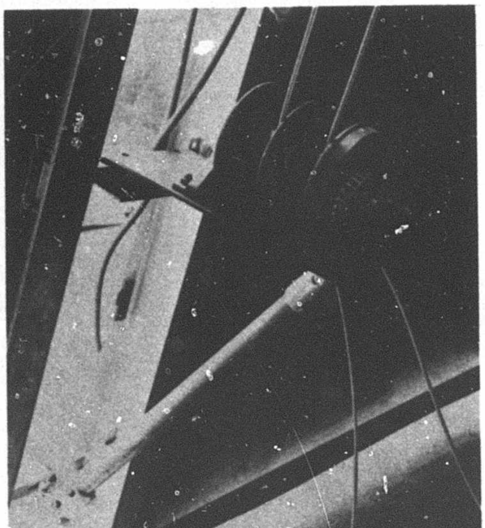


Figure 166. Hand Winch Mounted to Spacer Bars

The openable end wall is shown in its partially open and fully open modes in Figure 167 and Figure 168.

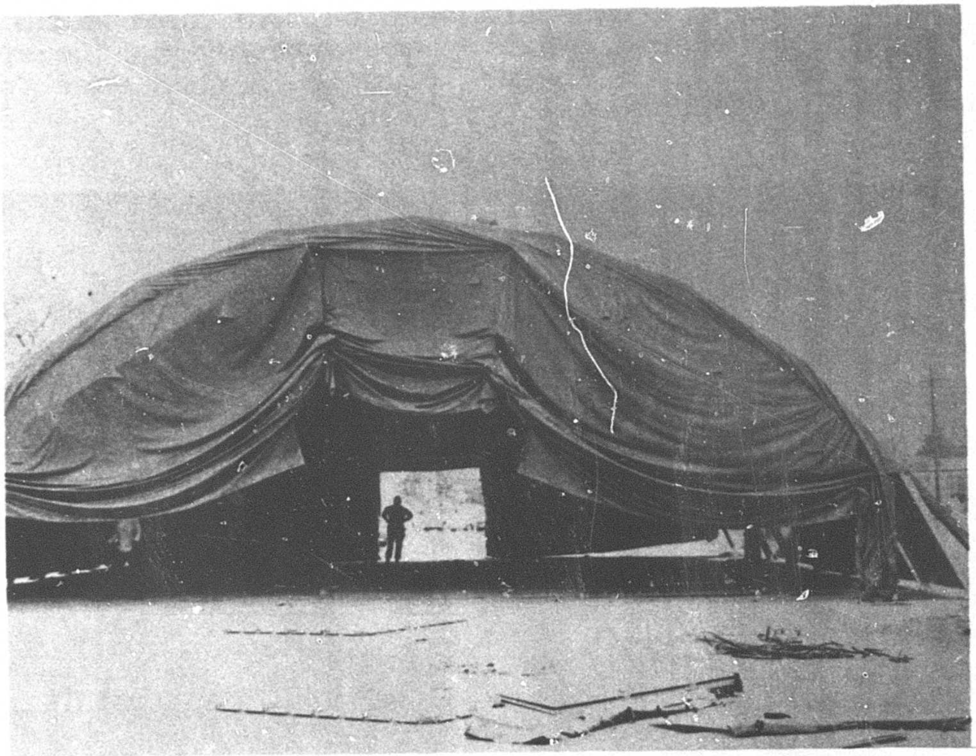


Figure 167. Partially Open End Wall

Figure 168. Fully Open End Wall

5. Fixed Fabric End Wall

The fixed fabric end wall and support columns are attached to the hangar in much the same manner as the openable fabric end wall.

The columns have integral jack devices for adjusting the column length. The jack bearing pads are retained to the base pads with steel pins. (Figure 169)

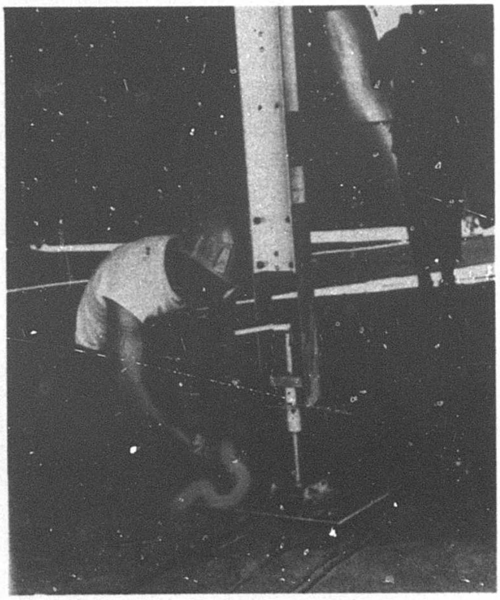


Figure 169. Column Adjusting Jack

This end wall has four support columns. The two center columns support a bi-folding truck door. These bi-fold door panels hinge to the side columns and are guided by rollers in a track on the door head beam.

The door head beam is hooked to each side column (Figure 170) and is pinned to the center (Figure 171).

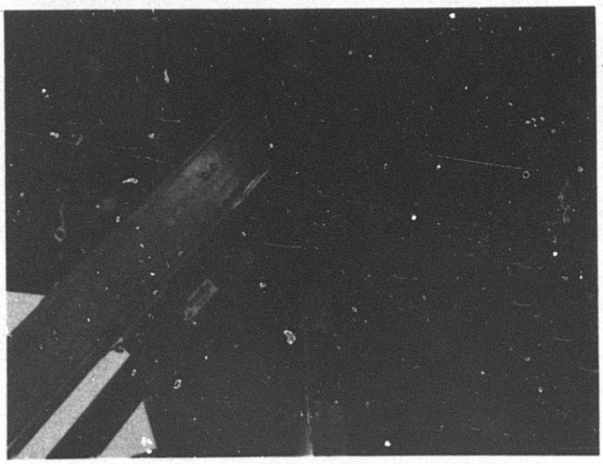


Figure 170. Door Head Beam Hooked to Column

Figure 171. Beam Pinned in Center

The truck door is the same on both the Hangar and General Purpose Shelter and is shown in Figure 195.

One problem encountered with the design of this end wall was that when the arch "kicked out" under its own weight the configuration changed so that all the fabric attachments could not be snapped to the arch rib beams. (Figure 172) This problem was eliminated on the second prototype by adding fabric "darts" over the truck door opening. (Figure 216)

6. <u>Rigid Panel End Wall</u>

A rigid panel end wall which incorporated seven standard arch double panel assemblies was designed and fabricated. This end wall, less counterflashing, is shown in Figure 173. The columns are the same aluminum "I" section used on the arch beams, and similar uses were made of the cam locks, spacers and beam hinges. Special panels were required to close out the arch configuration.

Figure 172. End Wall Partially Attached

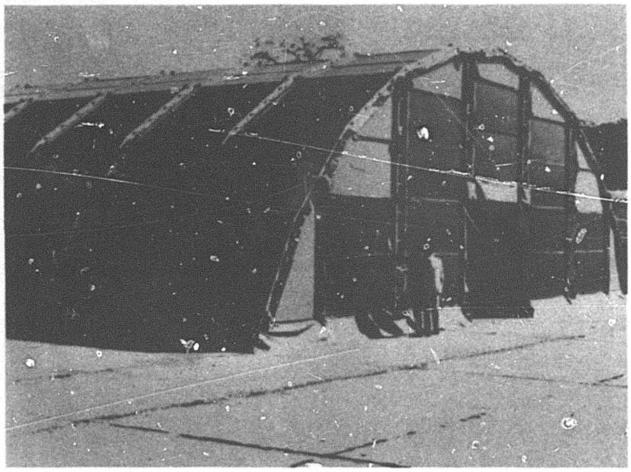


Figure 173. Rigid Panel End Wall

Special beam-to-panel clamps were incorporated to hold these special panels centered under the arch beams. (Figure 174)

It had been hoped that the columns and panels could be attached to the end arch during erection. However, two problems made this operation very difficult. First, the column sections had to swing up into a vertical plane relative to the end arch before panels could be attached. As shown in Figure 175 some panels could not be attached from the ground because the columns were in a vertical plane when the cam locks were too high to reach.

The other problem was that the panels were impossible to camlock in place if the arch was not properly restrained to hold the correct configuration. However, the columns were easy to attach and raise with the end wall arch, and the panels could be readily attached from raised platforms. A working platform on fork-lift tongs provided an excellent service for getting panels up into place.

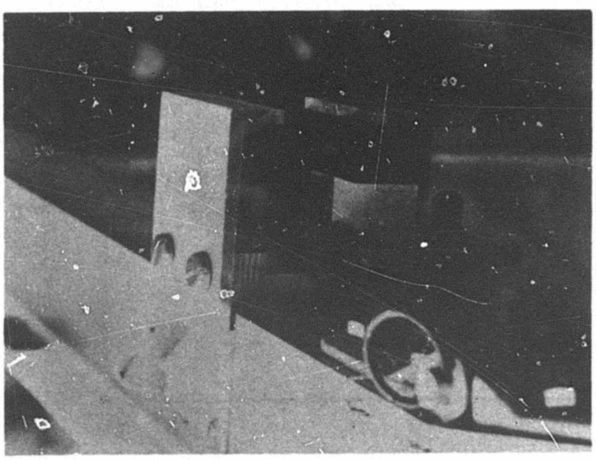


Figure 174. Beam to Panel Clamp

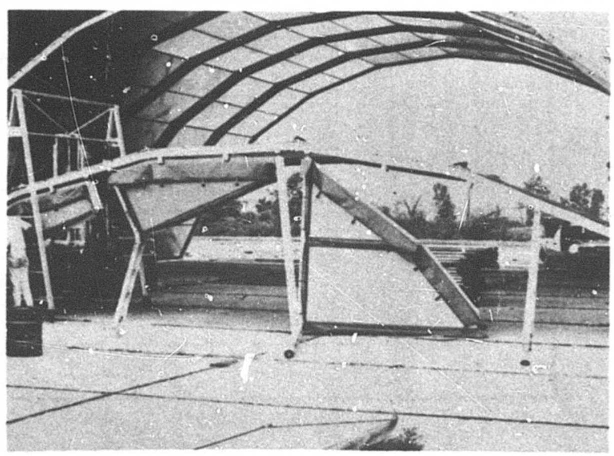


Figure 175. Attachment of Rigid Panels

7. <u>Electrical System</u>

The electrical system consisted of a distribution panel-board, fourteen wall outlets and fourteen light fixtures. (Figure 176)

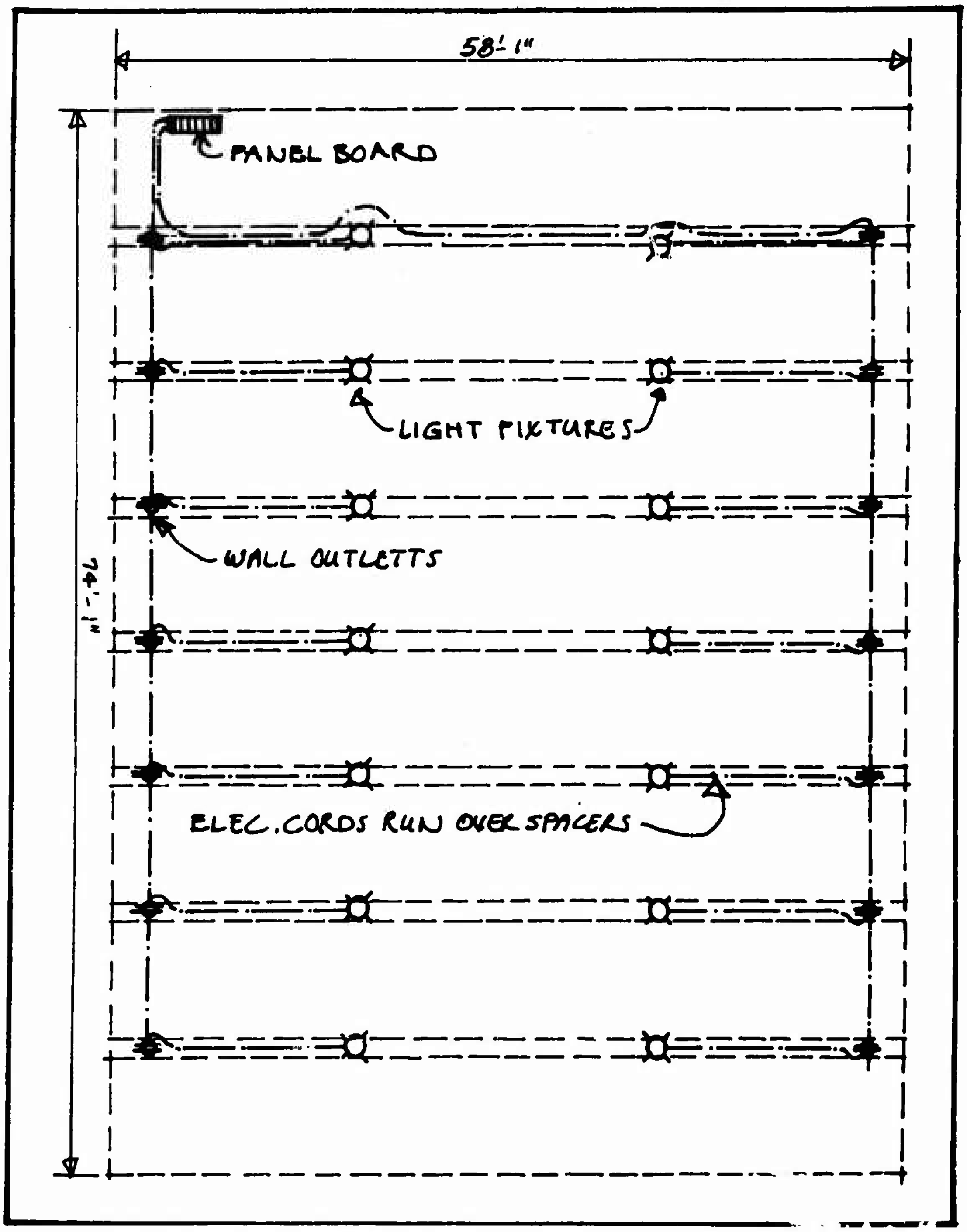


Figure 176. Electrical Plan

The distribution panelboard is located in the upper portion of the tool storage box. (Figure 177) Seven circuits are provided: two for the light fixtures, four for the wall outlets and one for an auxiliary power source at the panelboard.

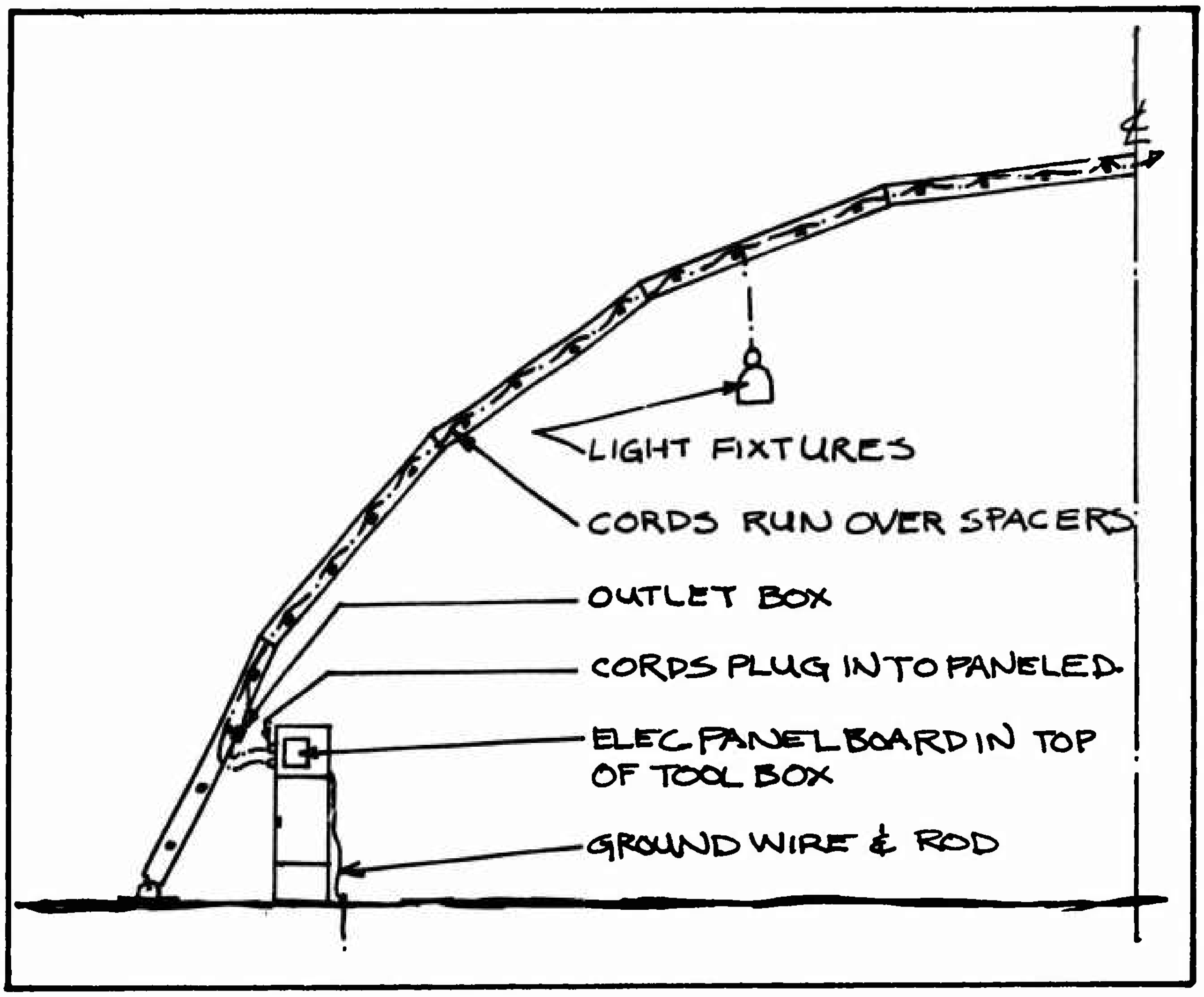


Figure 177. Section Through Half of Hangar

A 10' long service cable with a weatherhead (Figure 178) and a grounding cable was pre-attached to the panelboard and stored in the top of the storage box. A grounding rod was also provided and stored in the storage box.

Outlets were mounted in one side of the panelboard (Figure 179) for the two power distribution lines and the auxiliary power source.

The power lines are assembled in the field with waterproof twist-lock connectors. (Figure 180)

Light fixture cables plug into outlets at each junction box. (Figure 181) 150 watt light bulbs were provided with Teflon coatings for shatterproof protection.

Junction boxes were clamped to the arch beam spacers using the spacer-locking hand knob. (Figure 182)

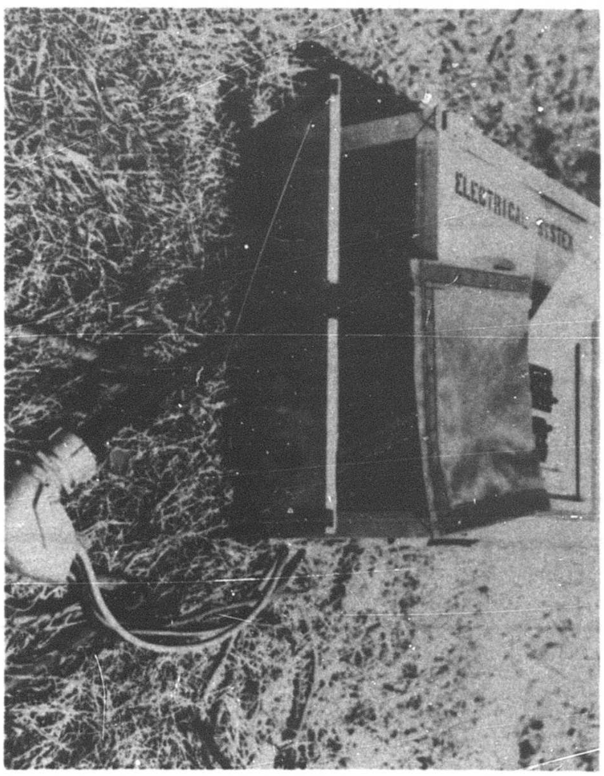


Figure 178. Top of Electrical/Tool Box

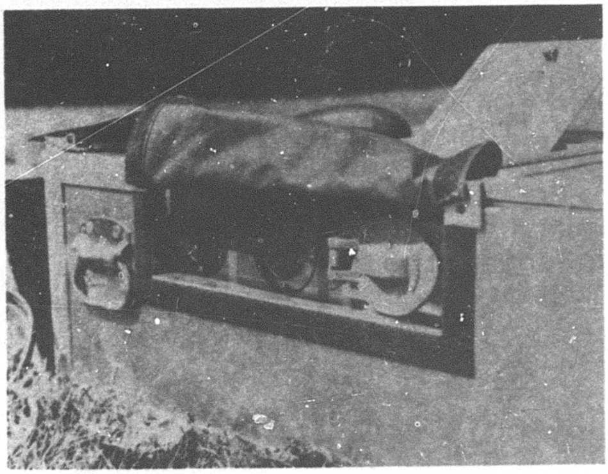


Figure 179. Side Outlets on Panel Board

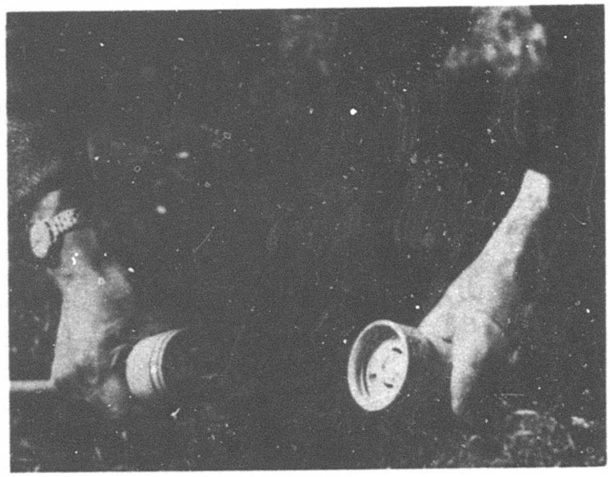


Figure 180. Twist-Lock Connectors

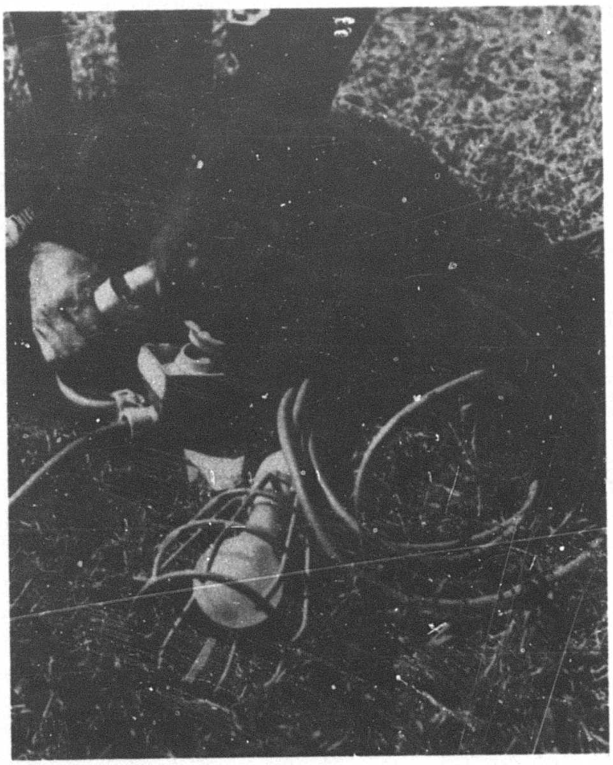


Figure 181. Light Fixture Plug to Junction Box

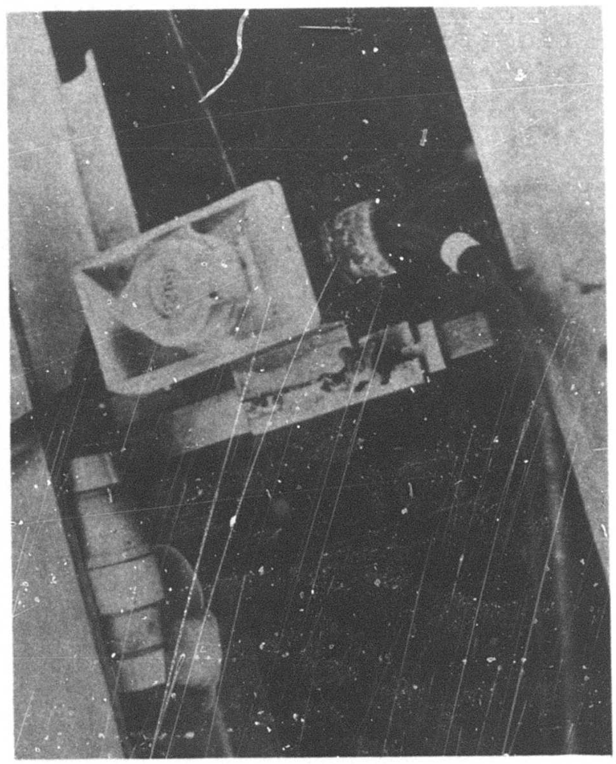


Figure 182. Junction Box Clamped to Spacer

8. Tool Box

Tools included in the tool storage box (Figure 183) included: The column locating device, four leather mallets for inserting hinge pins, four drift pins for removing hinge pins, four "T" handle Allen cam lock tools, two rollers for pressing down the "Velcro" on panel flashings, the base pad leveling device, four spacer hand knob tightening tools, the base pad layout cables, a repair kit, and the arch come-along with cable yoke assemblies.

9. Counterflashing

The last operation in erecting the hangar is installing counterflashing over the spacer gap between arches.

Fabric counterflashings with polypropylene chips (Figure 184) are used to close out the spacer gap between arches.

The rolled up counterflashing is carried up to the ridge of the hangar (Figure 185) and clipped to the top flanges of the arch beams (Figure 186) as it is unrolled.

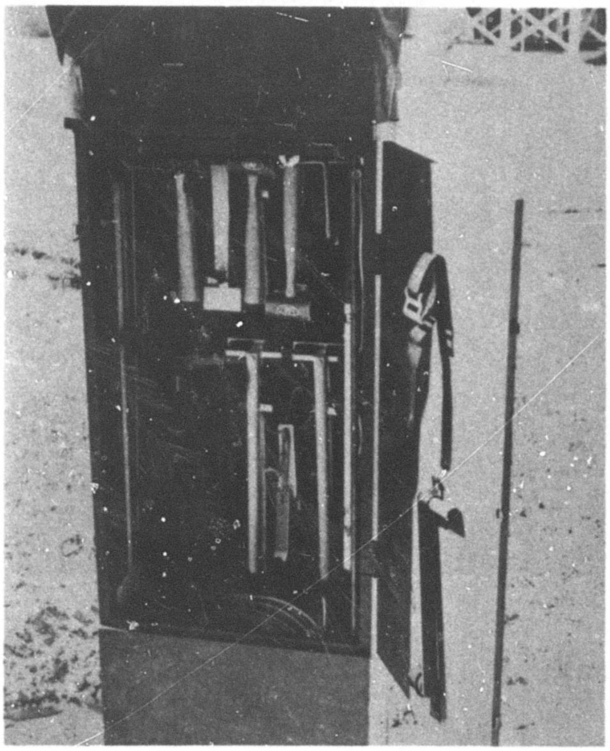


Figure 183. Tool Box

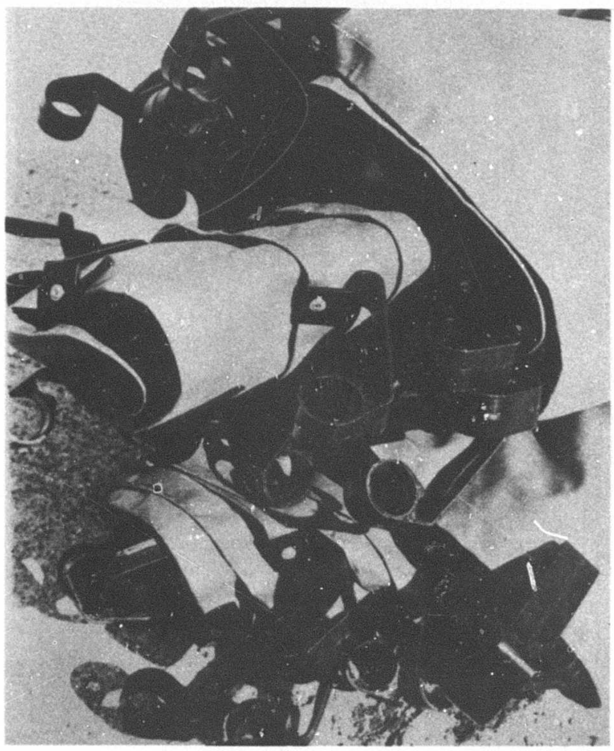


Figure 184. Folded-Up Counter Flashing

Figure 185. Counter Flashing Carried to Hangar Ridge

Figure 186. Counter Flashing Snapped to Beams

10. Packaging

The hangar components were strapped to 463L pallets for air shipment (Figure 187) and transferred by flat-bed truck (Figure 188).

Figure 187. Shelter Components Loaded onto C-130

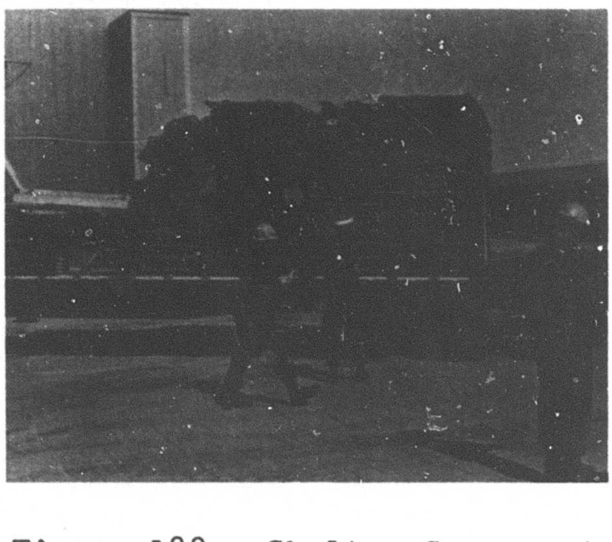


Figure 188. Shelter Components Transferred by Truck

The hangar required two and a half pallets for packaging. Therefore, two hangars will fit into one C-130 Type aircraft which has the capacity to lock five 88" x 108" pallets to its floor rail system. The packaged hangar weighs 16,000 lbs. Therefore, two hangars would be well within allowable load limits for short C-130 flights. However, for intercontinental flights the total load of 32,000 pounds would be approximately 3,000 pounds over the allowable load limit.

B. FIRST GENERAL PURPOSE SHELTER PROTOTYPE

As explained in Section V, the General Purpose Shelter configuration is achieved by using standard Hangar Components. Special components are required for the side wall "knee joints" and the end walls.

1. Knee Joint

The special angle required at the knee joint was achieved by adding a "hinge link" between the top standard beam hinges (Figure 189). As shown in Figure 190, the erection method is the same as for the Hangar except that the two knee joints receive three hinge pins instead of two.

The greater panel to panel dimension which occurs at the knee joint is flashed with a special flashing strip. (Figure 95) This strip is first attached to the standard panel flashing by engaging the "Velcro" with the hand roller. (Figure 191) Then it is mated to the corresponding "Velcro" on the side wall panels.

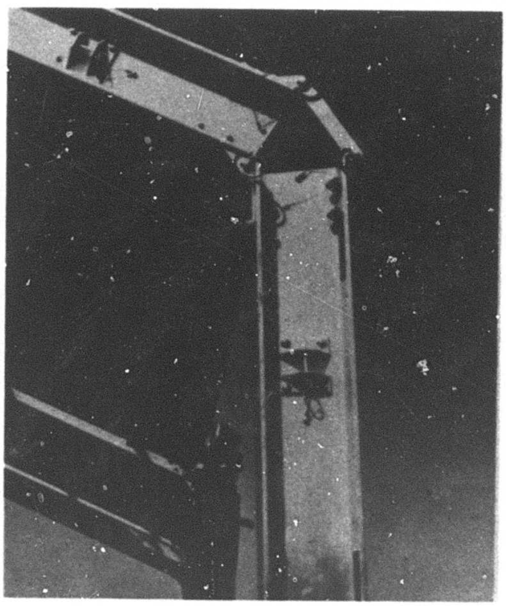


Figure 189. Knee Joint Hinge Link

Figure 190. Arch Erection Method

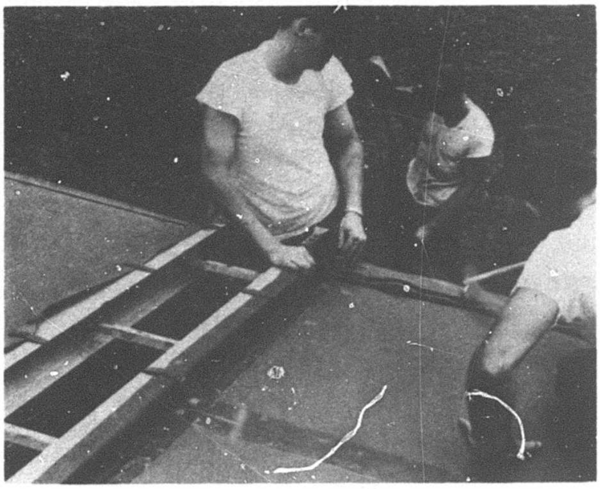


Figure 191. Special Flashing Strip Attachment

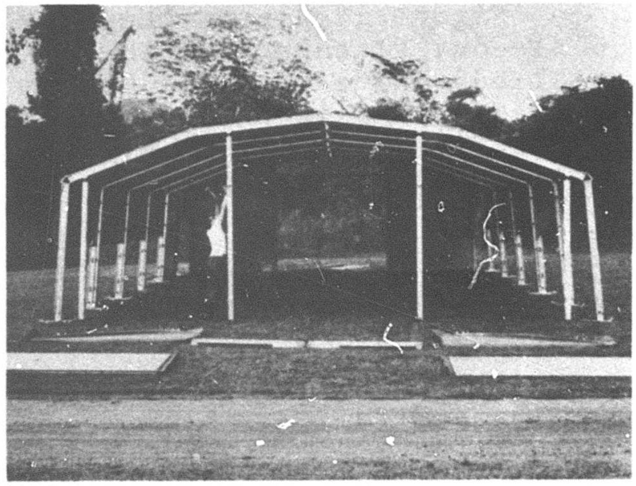


Figure 192. End Wall Columns Installed

2. End Walls

Both end walls are identical. Four special columns are required (Figure 192) and are clamped to the arch beams.

Two standard double-panel assemblies are camlocked to these columns (Figure 193). Two special panels are camlocked in place above the standard panels, and the door head beam, which is interchangeable with the Hangar door head beams, is installed. (Figure 194)

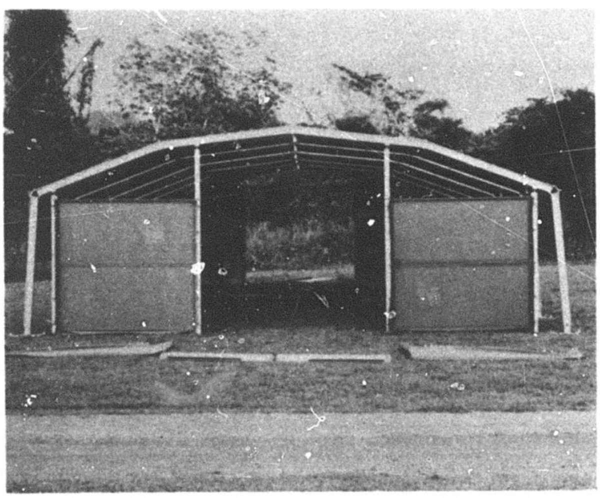


Figure 193. End Wall with Standard Panels

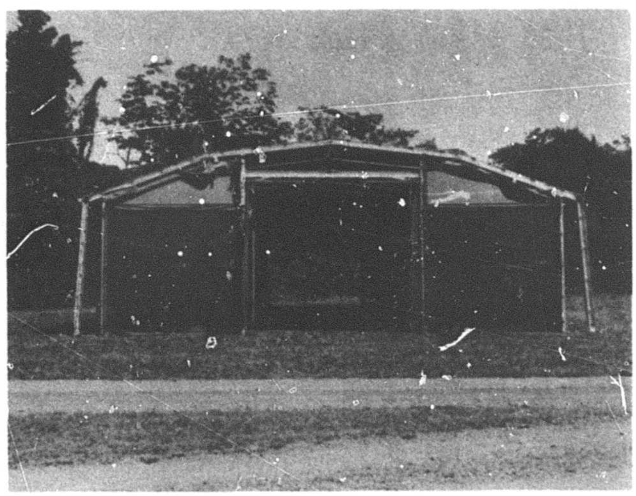


Figure 194. End Wall with Special Panels

Figure 195 shows the door head flashing, the arch beam close-out flashing and the six panel bi-fold truck door installed. Note that the bottom half of the sidewall panels are folded up. This provides ventilation in hot humid climates and is easily accomplished by simply unlocking the camlocks, unclipping the lower portion of the counterflashing and swinging the panel up.

Figure 196 shows a double personnel door unit which was designed for the entry and exit requirements of a mess hall.

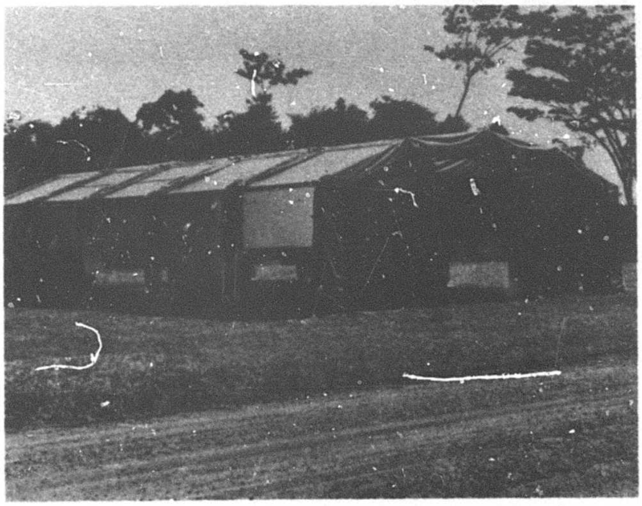


Figure 195. Finished End Wall

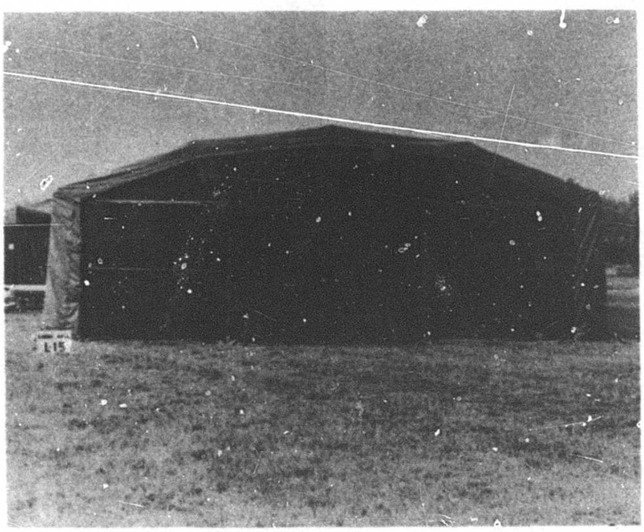


Figure 196. Double Personnel Door End Wall

C. FIELD TESTS

1. Panama Test

a. Objectives

The General Purpose Shelter was tested under tropical conditions at Howard AFB, Canal Zone, Panama. Howard AFB is located 5 miles west of the Panama Canal on the Pacific Coast. Representatives from the University of Cincinnati and the Aeronautical Systems Division (ASD), WPAFB were present for the 21 day test period (November 21 to December 13, 1968).

The test had several general objectives:

1.) To evaluate the ease and efficiency of erection and disassembly of the shelter in a tropical environment with an inexperienced crew.

2.) To evaluate livability in a tropical environment.

3.) To evaluate tropical weather effects on the shelter's materials and design.

b. Logistics

The shelter was transported from WPAFB to Howard AFB by C-130 aircraft via Lockbourne AFB, Ohio. The shelter was strapped to standard 463L pallets. No significant problems were encountered during on-loading, in-flight or off-loading.

Assistance was provided by the Civil Engineering Group, 24th Special Operations Wing, Howard AFB. The selected site was a small, slightly-rolling field next to a dense marsh. (Figure 197) There was no undergrowth, and the grass was cut weekly. Ground conditions were soft and moist from the daily rain. Soil-bearing conditions were not evaluated before erection.

The General Purpose Shelter in its packaged mode was brought to the site on a flat bed truck and off-loaded with a fork lift.

c. Erection

A crew of four enlisted personnel was provided to erect the shelter. Briefing was minimal, but the crew learned the erection procedure very quickly, and the shelter was erected in approximately 65 man hours.

In laying out the base pads a problem was encountered with the layout cable. The cable end stop sleeves were pulled off. This occurred because the steel cable had a nylon coating which was not stripped off at the points of stop sleeve attachment.

Figure 197. Erection Site

Three of the base pads were out of the level tolerances required as indicated by the leveling device. However, earth was not removed or added under these base pads as required because damage to the grass area would result. The resultant misalignment of arches was easily corrected by using the come-along to align the arches so that the spacer bars could be connected. One end of the come-along was clamped to the top of one arch side wall beam, and the other end was clamped to the top of the opposite side wall beam of the other arch. Then the arches were cranked into alignment. The spacers were carefully inspected after the shelter was taken down, and no damage was evident.

Each base pad was staked down with four stakes. Two types of stakes were used for comparative purposes. The 2" x 2" aluminum "T" shaped stakes were far more effective than the 3/4" diameter steel stakes in the soft earth because of the larger bearing and friction area provided by the "T" section.

While the base pads were being staked down, the rest of the crew started unloading the pallet. Because the beams were packed by beam type, the entire pallet had to be unloaded to get the four types needed to put up the first arch. Grouping the beams by arch rather than beam type would have simplified the initial setup.

The erection gantry had a double barrel hand winch to facilitate raising both sides of an arch with the one winch. Initially steel cables had been used but, due to uneven spooling of the cable, 1-1/2" wide nylon webbing was used in this test to try to eliminate this problem. However, the elongation under loading of this webbing caused the arch to be raised unevenly because one strap is 9' longer than the other. This problem was later solved by using a low-elongation polyester webbing.

The leather mallets provided for driving the hinge pins were not thought to be durable or heavy enough. Weighted plastic mallets with replaceable heads were recommended.

It was found that it was easier to attach the last arch beams to the base pads if the last double panel assembly were left off until after the arch was attached to the base pads.

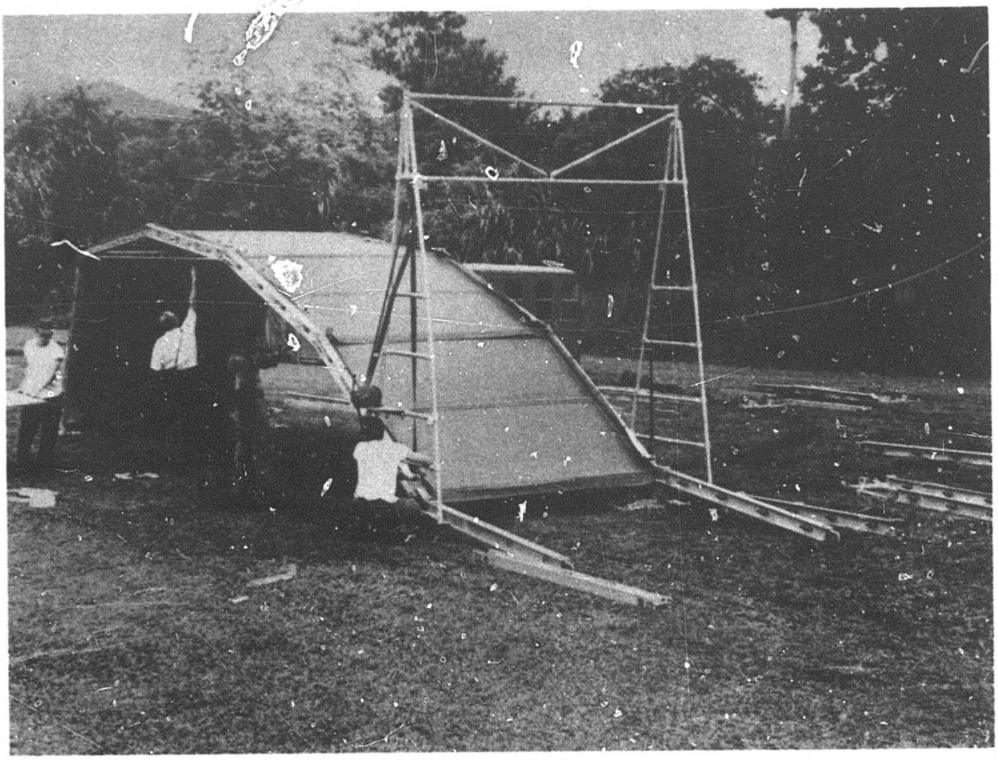


Figure 198. Last Two Beams Raised Without Panel

Since this arch only kicks out a few inches under its own weight, it could be simply pushed in with a crowbar when attaching it to the base pads. Therefore, a crowbar was recommended for inclusion in the tool kit.

The erection gantry required 2 x 4's under its wheels to prevent it from sinking into the water-soaked earth. Larger wheels would help alleviate this problem.

On this shelter, rope had replaced the plastic clips (Figure 184) on the counterflashing. The rope was sewn into both edges of the counterflashing and, when pulled tight and tied off to cleats mounted to the base pads, the counterflashing would seal against the panel side flashing. However, for this test, the cleats were improperly located on the base pads so that the rope was pulled away from the panels on the side walls. It was recommended that the cleats be moved in closer to the panels to offset this problem.

The end wall columns, panels and flashing were erected without any difficulty, but the truck door presented a problem. The folding door panels were hinged to an aluminum "T" shaped extrusion which was, in turn, bolted to the side columns with four bolts (two at top and two at bottom). The columns contained threaded inserts so that the four bolts could be adjusted to square the door. Tightening of one of these bolts would tend to bind the other three bolts. This door jamb detail was later refined so attachment and adjustment could be achieved with only one bolt at top and one at bottom. This method performed satisfactorily. However, since this door design did not perform well when used primarily as a personnel door, it was re-designed to be a center-parting rolling truck door with a conventional personnel door in one of the sliding panels. (Figure 225)

d. Weather Conditions

During the first four days of this test, heavy rainstorms were encountered each afternoon for four or five hours. At one point, rain fell at a rate of two inches per hour.

The next four days were dry and sunny. Light to medium scattered rain occurred during the final two weeks of the test.

Temperatures ranged from the 70's at night to the high 80's during the rainy days up into the low 90's during the dry days.

The barometer stayed around 30 inches throughout the test, and the humidity ranged between 70 and 80%.

e. Test Apparatus

The main source of test information was a "Brown" 12-track temperature recorder using thermistor wire. Temperatures were taken at 3 points on the General Purpose Shelter and one probe took ground temperature readings. Barometric pressure, relative humidity and temperatures were recorded every half hour from 9 a.m. to 5 p.m.

f. Weather Test

The General Purpose Shelter was tested with the doors at both ends of the shelter open. The ground inside the structure remained muddy throughout the three-week period. No significant leaks developed, and no ultra-violet effect was observed on the fabric flashing. Temperature probes were located on a middle arch roof panel. One probe was located on the outer skin, one on the inner skin, and a third probe was located 12" beneath this panel measuring the inside temperature. Average inside and outside panel skin temperatures are shown in Figure 199. Average inside and outside ambient temperatures are shown in Figure 200.

g. Disassembly

The shelter came down easily and much faster than expected. Only 45 man-hours were required. Just as noted in the erection procedure, disassembly was sped up by removing the side wall panels before lowering the arch and disconnecting the side wall arch beams. Panels were stacked on the pallets as the shelter was disassembled, and beams were staked for strapping together.

In taking up the base pads, the crowbar was a valuable tool for pulling out the stakes. After the shelter was completely disassembled, only 3 hours were required to stack and band all components to the pallets for shipment.

2. <u>Eglin Test</u>

The Hangar was tested at Eglin AFB, Florida. The shelter was erected September 23-26, 1968 and disassembled January 27-29, 1969. Representatives from the University of Cincinnati and the Aeronautical Systems Division (ASD) WPAFB were present for the erection and disassembly phases of the test.

a. Objectives

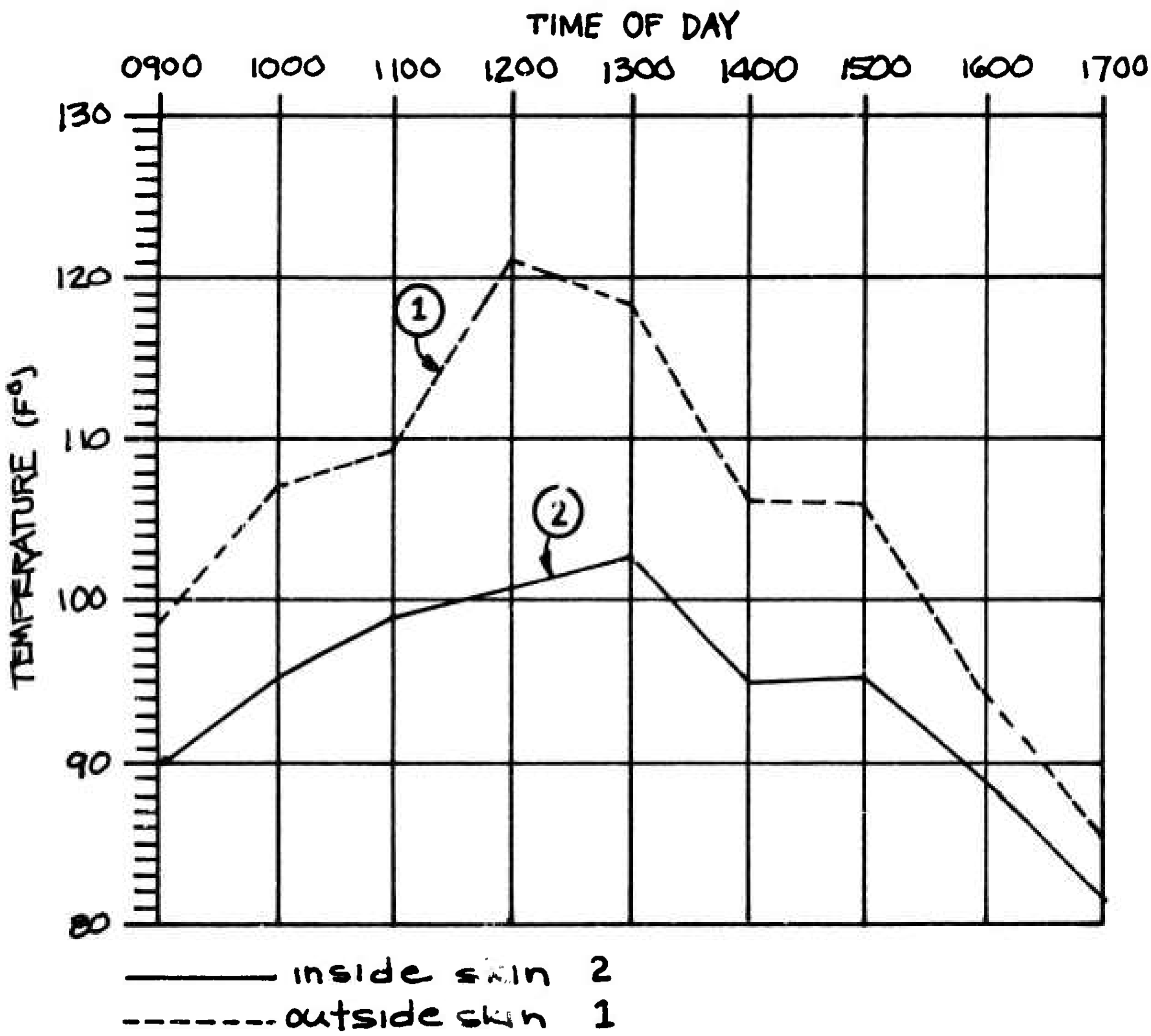
1.) To evaluate the ease and efficiency of erection and disassembly of the shelter by an inexperienced crew.

2.) To evaluate the shelter's livability and functional characteristics.

3.) To evaluate weather effects on the shelter's materials and design.

b. Logistics

The Hangar was flown to Eglin AFB on a C-130 aircraft. The components were strapped to three 88" x 108" 463-L pallets Two pallets were fully loaded and one was half loaded. At Eglin AFB the pallets were off-loaded onto a flat bed truck and transported to the erection site. Some difficulty was exper-



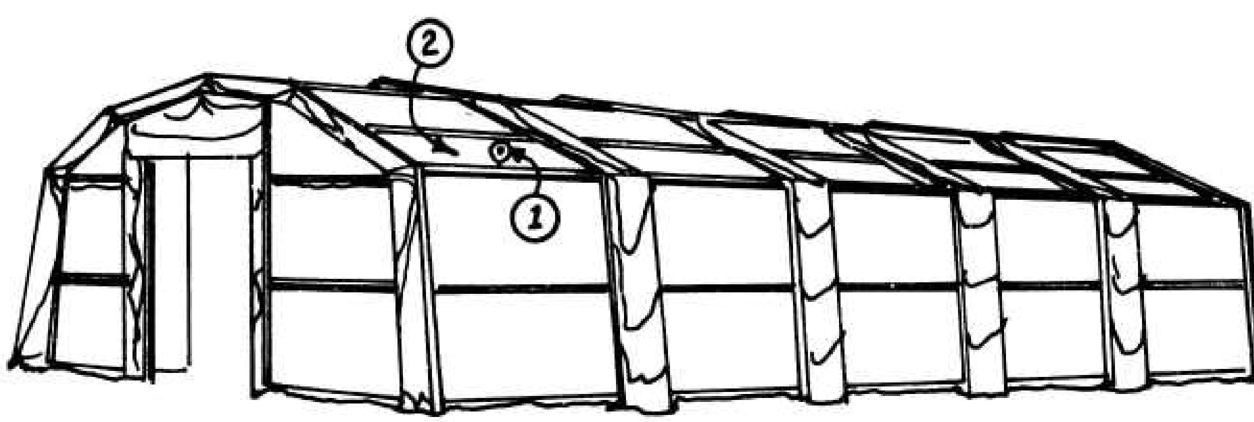


Figure 199. Panel Skin Temperatures

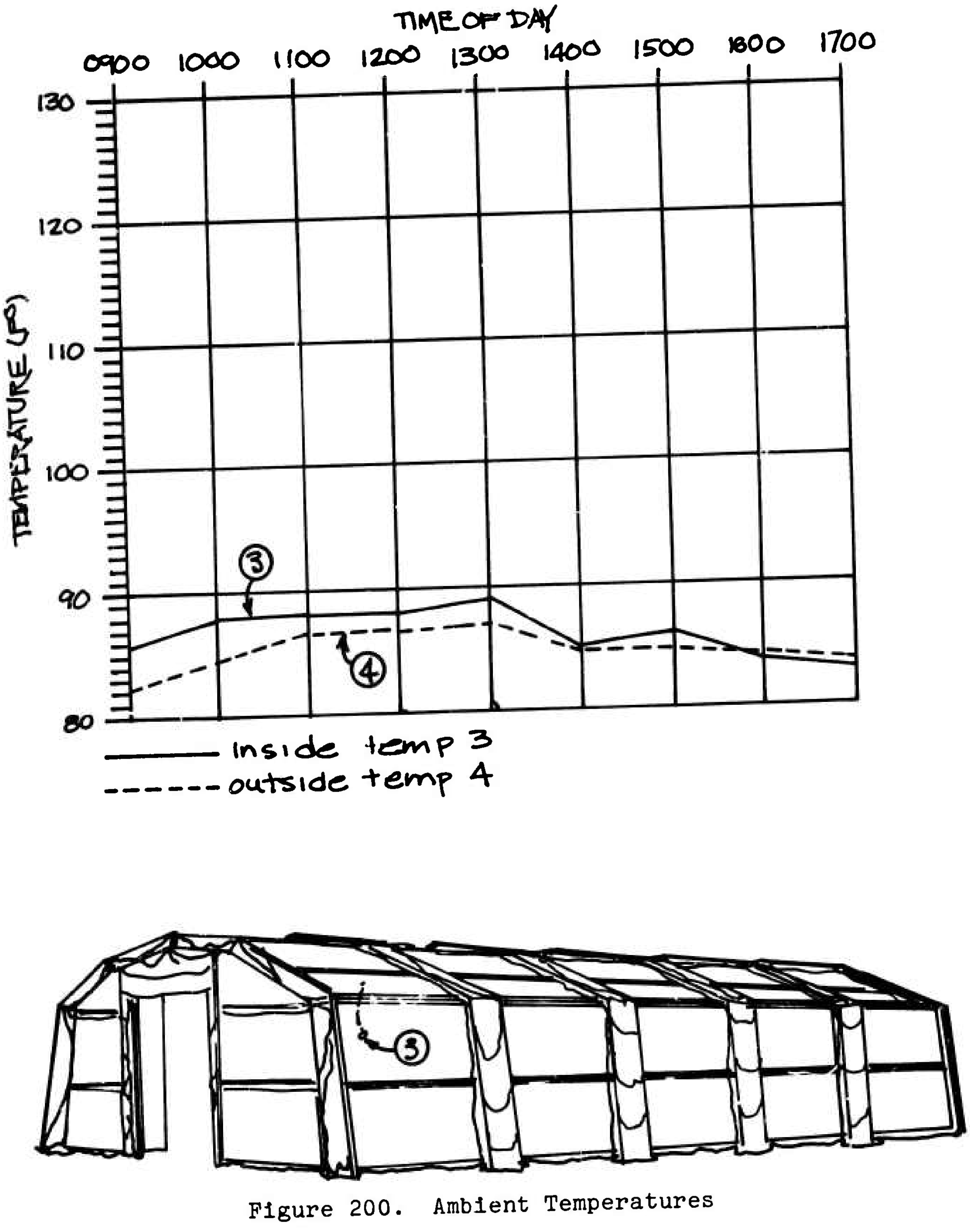


Figure 200. Ambient Temperatures

ienced in getting the loaded pallets off the truck because no fork lift that could unload the pallets from the side of the truck (the long dimension of the pallets) was available. These pallets were lifted and lowered to the ground by a crane and sling arrangement. (Figure 201) Although no damage was done to the hangar components, this method of off-loading is not recommended. Either the pallets should be loaded on the truck with the long dimension parallel to the bed length so that a fork lift can get its prongs under the short dimension of the pallet or, if the distance is not too great, the pallets should be transported from the plane to the erection site by fork lift.

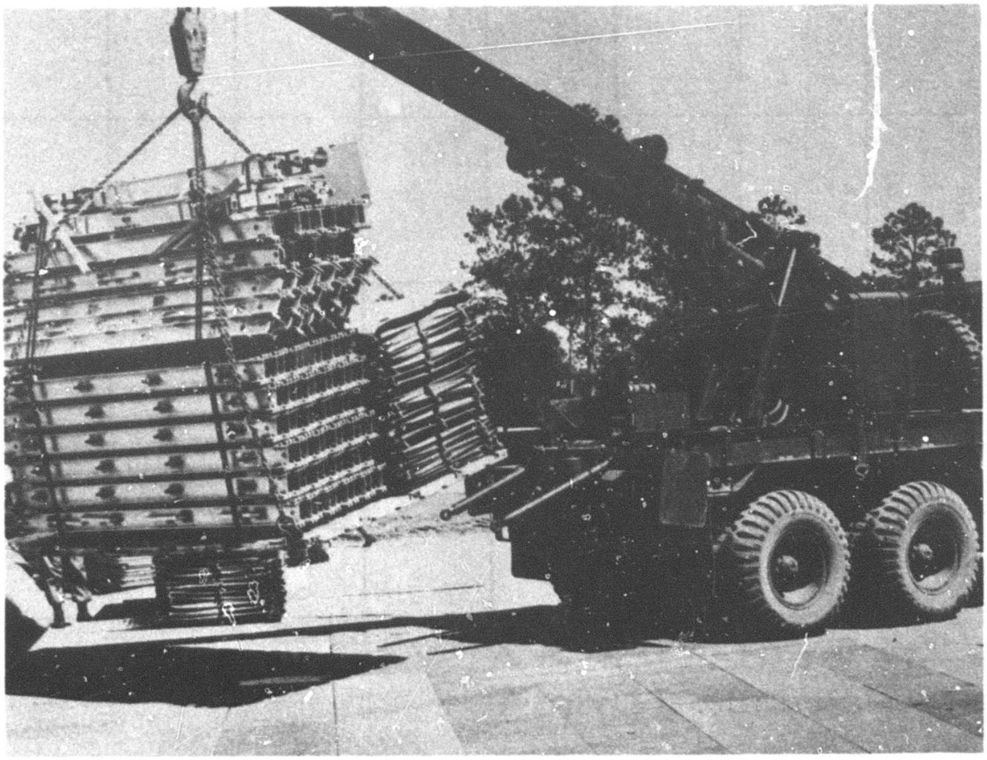


Figure 201. Off-Loading Pallets From Truck

c. Erection

A crew of eight enlisted men was provided for erecting the shelter. Sequential photographs of this erection were used in the description of the first Hangar prototype - found in Section VII, A, FIRST HANGAR PROTOTYPE.

The erection by the crew, which was unfamiliar with the shelter system, generally went smoothly. The crew chief read the erection manual prior to starting the erection, and very littl. reference to this manual was required during the erection. The crew caught on to the erection procedure quickly, and once the first arch had been erected, the crew's learning curve showed a definite upward trend in that time for erecting each succeeding arch was reduced.

Approximately 180 man hours were required for this erection. A substantial time was spent in the initial unloading of components and familiarization of the crew to these components. An estimated 50 to 80 man hours could be saved in subsequent erections of this shelter by the same crew.

d. Weather Conditions

Temperatures during the test period ranged from 70° to 80° during the day and dropped to between 40° and 50° during the night. Most of the days were clear and warm with occasional scattered showers. A small amount of leakage was reported where blowing rain worked its way between the counter-flashing and panel flashing. The principal problem encountered was with condensation dripping from the arch beams. Fabric flashing, which would cover the bottoms of these beams, was recommended. This flashing would form a gutter and would not only create a path for condensation to run off but would also control rain leakage from the counter flashing.

e. Disassembly of the Shelter

A crew of 7 enlisted men who were unfamiliar with the shelter was assigned to dismantle and package it for shipment back to Wright-Patterson Air Force Base.

The crowbar was found to be very useful in relieving pressure on the base pad/arch attaching bolt so that it could be removed.

Again, the crew's learning curve showed a definite upward trend with a first arch disassembly time of two hours and a fourth arch disassembly time of fifty five minutes.

An effective disassembly procedure was worked out for this crew. It relegated different operations to each crew member:

1. One man operated the gantry hand winch
2. Two men attached the lifting clamps and removed hinge pins
3. Two men disconnected and stacked the panels and beams
4. Two men disconnected spacer bars on the next arch

After all arches were down and the end wall was folded, the men were assigned the following tasks:

1. Four men began stacking panels and beams onto the pallets

2. Two men removed the base pad stakes and stacked the base pads on the pallets

3. One man coiled up the ground cables and then assisted in the packaging

The dismantling and packing of components onto the pallets required 90 man hours.

VIII

SECOND PROTOTYPES

The second Hangar and General Purpose Shelter prototypes were delivered to Wright-Patterson Air Force Base in July, 1969. Also, the first hangar and general purpose shelters were refurbished and delivered with the second prototypes. This refurbishment involved updating the first prototypes to include all improvements made on the second prototypes. A complete set of working drawings and specifications covering the second prototype and modifications required to refurbish the first prototype was delivered to the Project Officer on 26 December, 1969. All four shelters were test erected at WPAFB prior to being shipped out for field test. These shelters were erected and monitored by the contractor at Seymour-Johnson Air Force Base, North Carolina to familiarize the Air Force crews with their erection methods prior to deployment to North Field, South Carolina for testing in the Coronet Bare Exercise.

Fabrication of these shelters was performed by the subcontractors who built the first prototypes except that the fabric components were fabricated by Rubber Fabricators, Inc., Grantsville, West Virginia and the electrical components were fabricated by Mutual Electric in Dayton, Ohio.

A. HANGAR IMPROVEMENTS

The second hangar prototype reflected many improvements in the design of components based upon problems encountered during field tests of the first prototypes and continuing investigation. The following describes these design changes both as reflected in the second prototypes and as incorporated in refurbishing the first prototypes.

1. Base Pad Layout and Anchoring

Base pad layout was simplified with the use of spacer ground angles (Figure 202) which attached between adjacent base pads. The ground angle also serves as a means for closing out the bottom panel flashing. (Figure 203)

The double bolt clamp assembly on these base pads serves two functions other than holding the ground angles. First two gripper blocks hold the cables of "arrowhead" anchors which prevent the base pads from lifting off the ground when high winds are blowing on the hangar. The "arrowhead" shaped anchor (Figure 204) is driven into the ground with a gasoline

Figure 202. Base Pad with Ground Angle

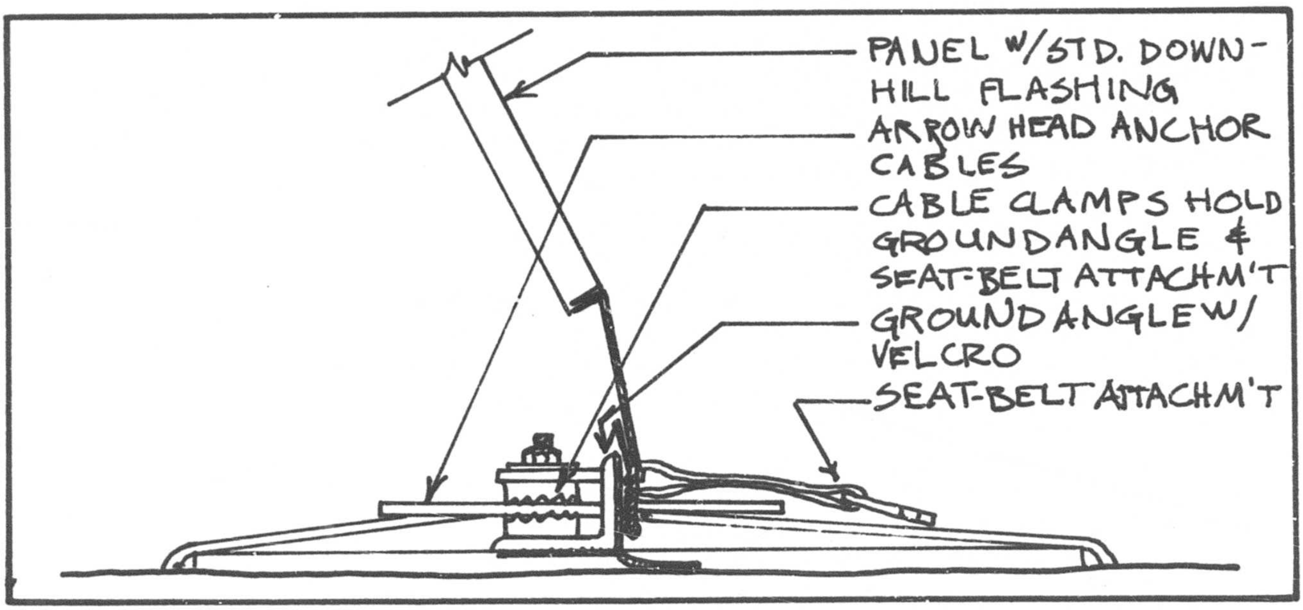


Figure 203. Panel Flashed to Ground Angle

engine powered driving device (Figure 205). Four are driven for each base pad, and their cables are clamped by the base pad grippers. With the use of the "arrowhead" anchors, the ground cables used on the first prototype (Figure 135) were no longer needed. The other function is the seat belt attachment received the mating half from the counterflashing (Figure 222).

See Appendix D for base pad analysis.

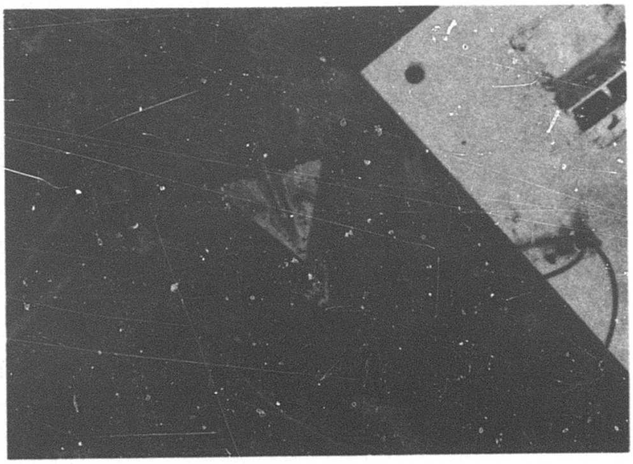


Figure 204. Arrowhead Anchor

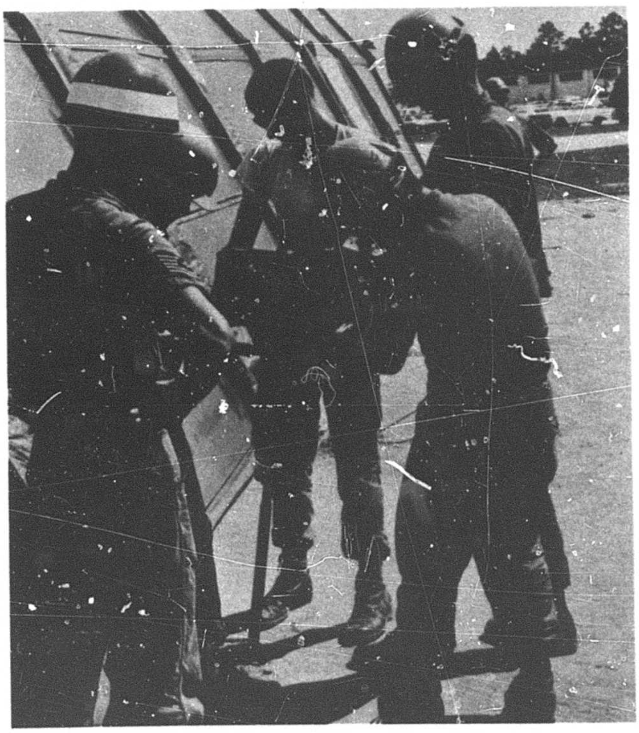


Figure 205. Power Anchor Driver

2. Erection Gantry

The erection gantry was improved in several ways for the second prototype. As shown in Figure 206, the top horizontal structural member has been changed to an aluminum "I" beam. This beam is attached to the side "A"-frame members with standard arch beam connectors. The resultant gantry is much easier to assemble and is stronger. The hand winch is mounted permanently and is changed to a worm-gear type for safety reasons. The first gantry had ratchet type winches which presented a safety hazard if the reversing cog were left in the neutral position. Also the worm-gear type winch could be operated with an electric motor to speed erection should power be available during the erection phase.

3. Arch Beams

The arch beam used on the first prototype (discussed in VII, A, 3) was changed to a 5-1/2" x 3" aluminum, 6061-T6 alloy, "I" beam section which weighed 3.09 lb/ft (Figure 207). This new section was specifically extruded for this job so as to achieve a weight saving on one hangar of over 400 pounds. Even though this beam section is lighter than the other previously used, its greater depth made it stronger. It had an I value of 13.370 in^4 compared to 12.260 in^4 on the prototype arch and 13.59 in^4 on the first full size shelter prototype.

See Appendix D for beam, hinge spacer and camlock analyses.

4. Double Panel Assemblies

The horizontal flashing joints were improved by interlocking of fabric flaps. (Figure 208)

The vertical (panel to beam) flashing was changed to incorporate continuous "Velcro" attachment to the arch beam (Figure 209).

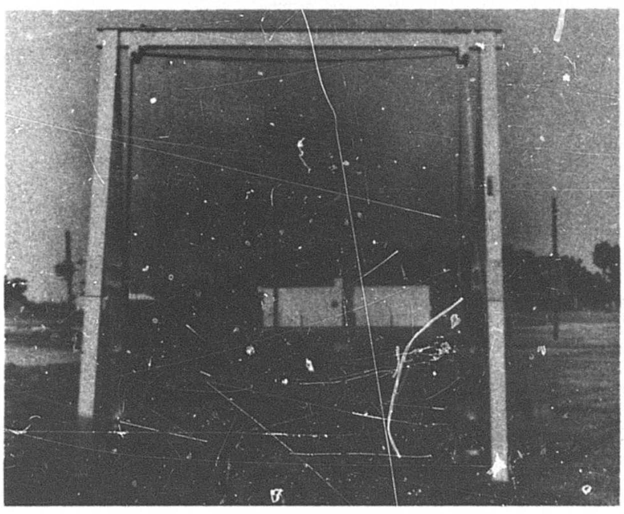


Figure 206. Erection Gantry

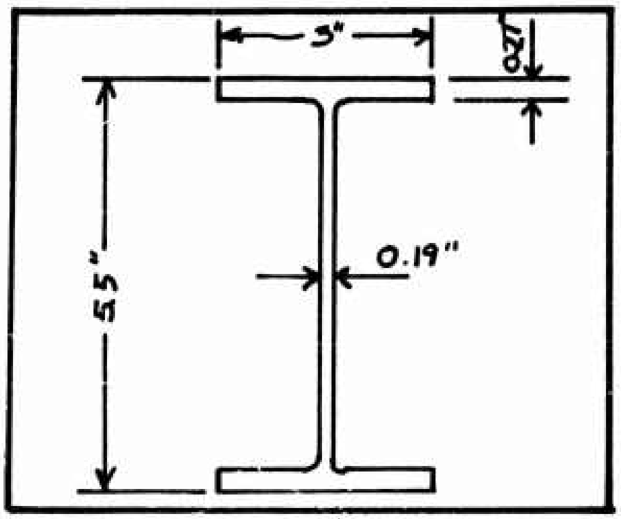


Figure 207. Arch Beam Section

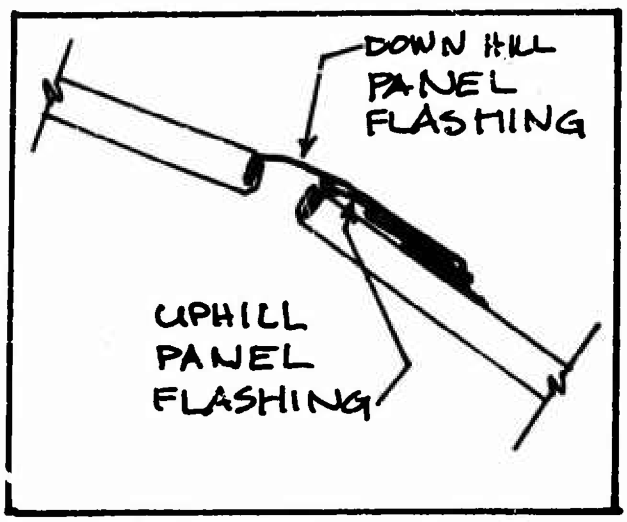


Figure 208. Horizontal Panel Flashing

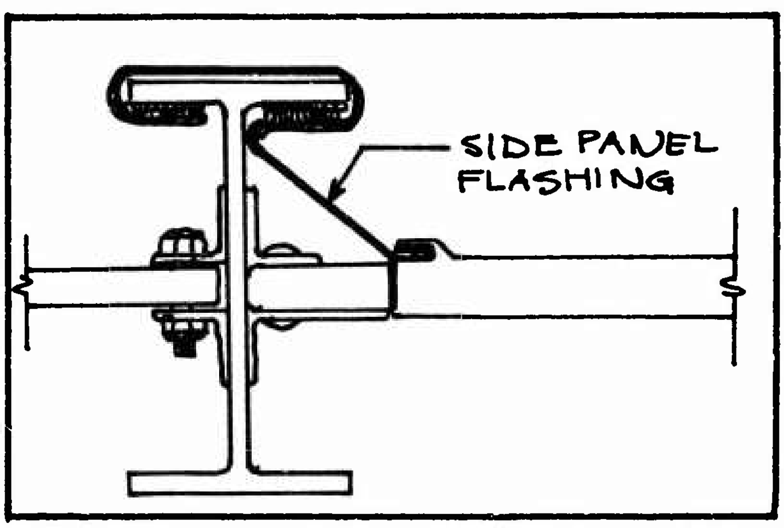


Figure 209. Vertical Panel Flashing

Four double panel assemblies on each side of the Hangar received window and plain knockout panels (Figure 210). Light proof ventilation and heater duct connector panels were supplied to replace the plain knock-out panels when required. The windows were provided with black-out curtains.

5. Openable Fabric End Wall

The openable fabric end wall was completely re-designed to improve ease and speed of operation. Also improvements were made in reinforcing and weatherproofing details.

The swing-up columns (Figure 158) were deleted by increasing the size of the end arch beam sections. Figure 211 shows the beam section required for the openable end wall attachment. See Appendix D for structural analysis of this beam.

Figure 210. Window and Knock-Out Panels

Figure 212 shows the method of joining these larger arch beams. Double hinges are used at top and bottom to resist the increased beam stresses. Also aluminum plates are welded to each beam end to prevent bending of beam flanges.

The many end wall snap attachments to the ground on the first prototype design were eliminated from the door opening procedure by attaching the fabric to ground beams. The wind load on the fabric end wall is transferred to this ground beam which is, in turn, locked to the ground (Figure 213) by six

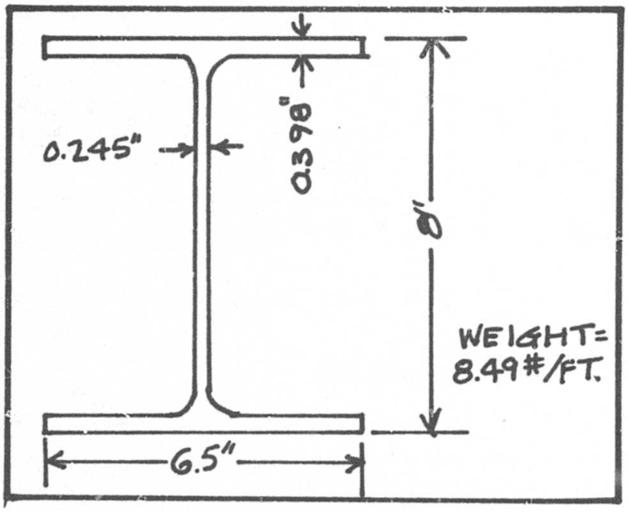


Figure 211. End Arch Beam Section

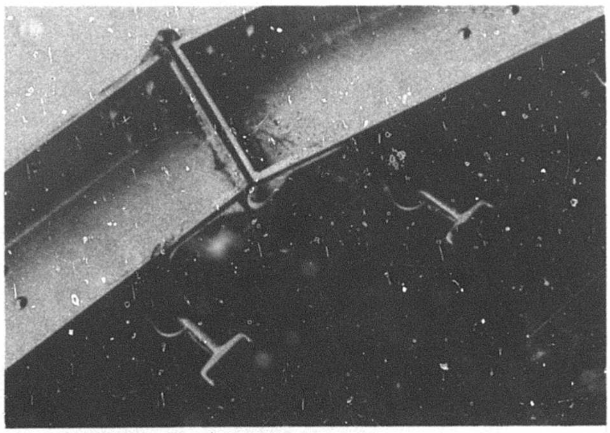


Figure 212. End Arch Beam Joint

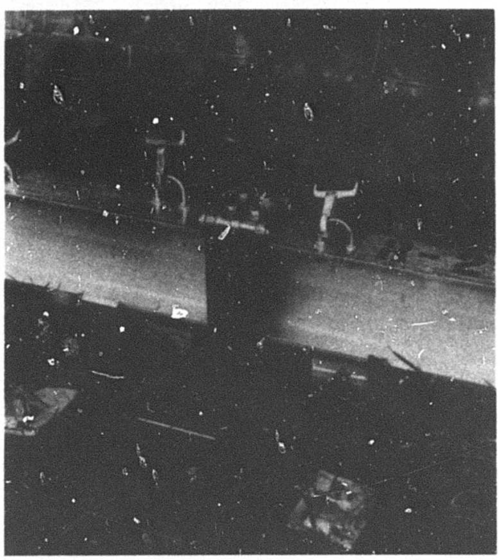


Figure 213. Lock Down Base Pads

lock-down base pads. The spring loaded clamps on the ground beam automatically engage with the base pads when they are dropped into place as the door is closed. Stepping down on the foot lever disengages the clamps and holds them open until the ground beams are raised, along with the end wall fabric, with the hand winch cable and pulley system. (Figure 214)

Figure 215 shows this end wall in its open configuration.

6. Fixed Fabric End Wall

Principal design improvements over the first prototype end wall were the addition of two fabric darts over the truck door, and the sliding truck door. (Figure 216) The darts allow the fabric to be attached to the arch as it kicks out during erection. The truck door is less complex and easier to operate than the first prototype, and a personnel door is incorporated in one of the sliding panels.

A greatly improved method of flashing both the Openable and Fixed Fabric End Walls to the arch beams was incorporated in the second prototype. A continuous rubber gasket was adhered to the arch flashing flaps. This engages the top beam flange as shown in Figure 217. Note that the panel side-flashing is sealed at the same time.

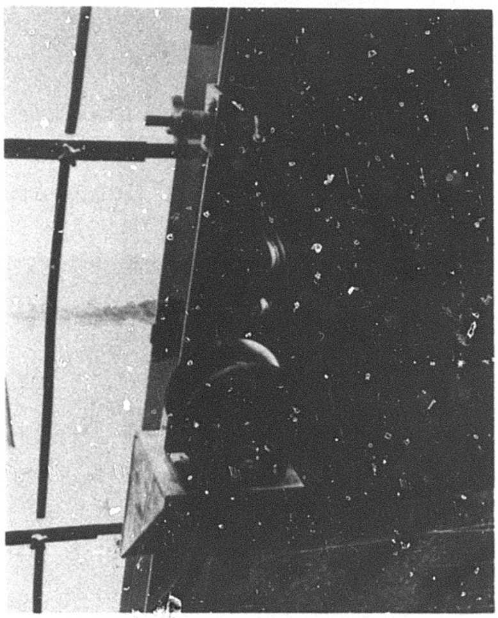


Figure 214. End Wall Raising Hand Winch

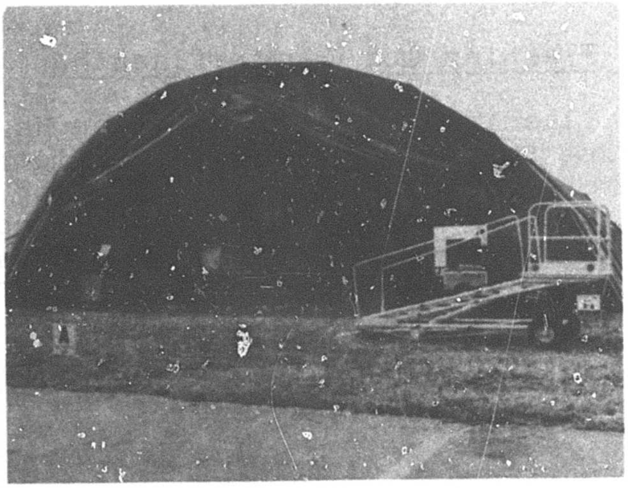


Figure 215. End Wall in Open Configuration

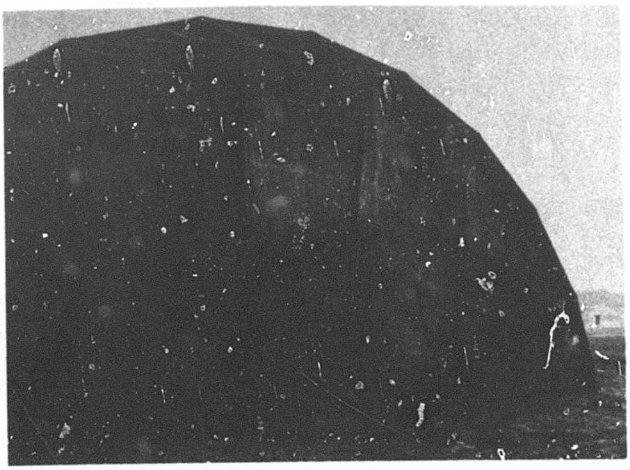


Figure 216. Fixed Fabric End Wall

Figure 217. End Wall Gasket Flashing

7. Gutter Flashing and Counterflashing

The gutter flashing is attached to the Hangar arch beams prior to attaching the counterflashing. (Figure 218) It is attached by climbing up the spacers on the top of the shelter and reaching in through the spacers to hook successive grommets in the gutter flashing over carriage-head bolts in the beam's bottom flanges. As explained in Section VII, C, 2, d, the gutter flashing is required to prevent condensation from dripping off the arch beams.

The counterflashing (Figures 219 and 220) is a continuous fabric covered plywood flashing which is pulled up over the shelter (Figure 221) and is held down on outboard sides of the adjacent arch beams by steel cables. These cables are attached to base pads at each end by "seat belt" straps and buckles which are pulled tight to secure the counterflashing. (Figure 222)

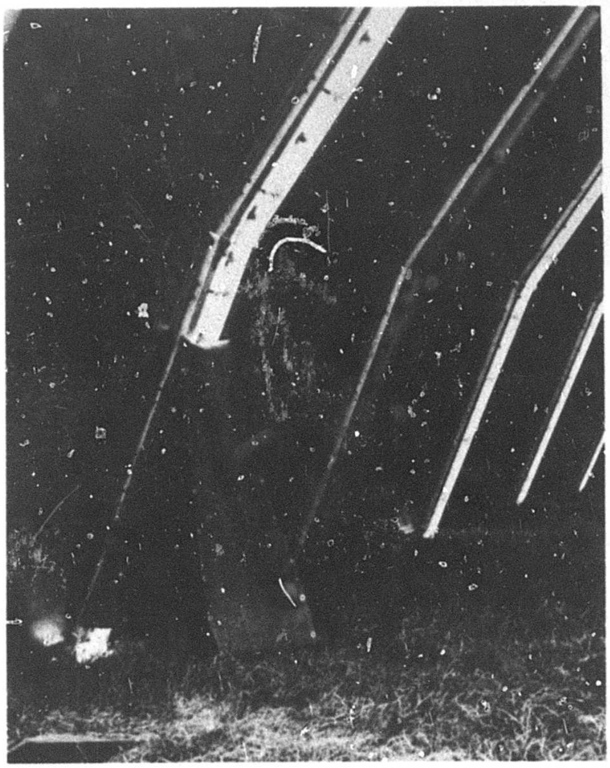


Figure 218. Gutter Flashing

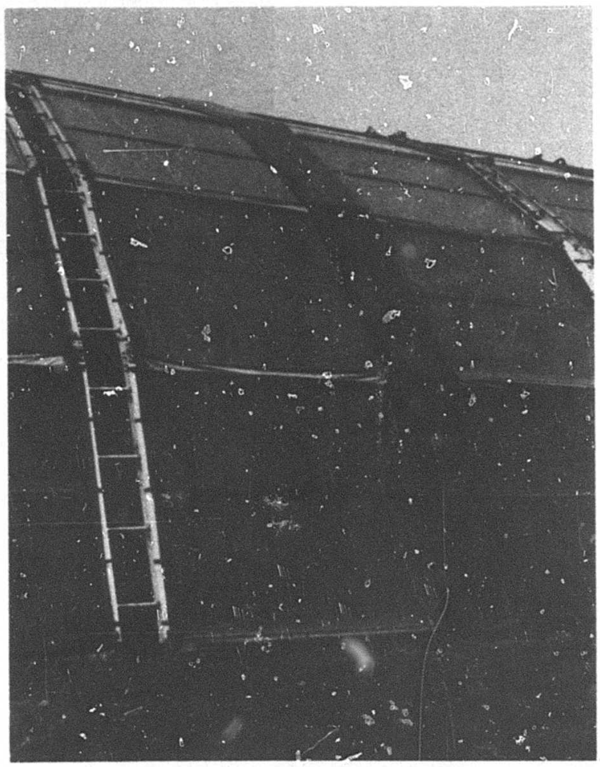


Figure 219. Counter Flashing

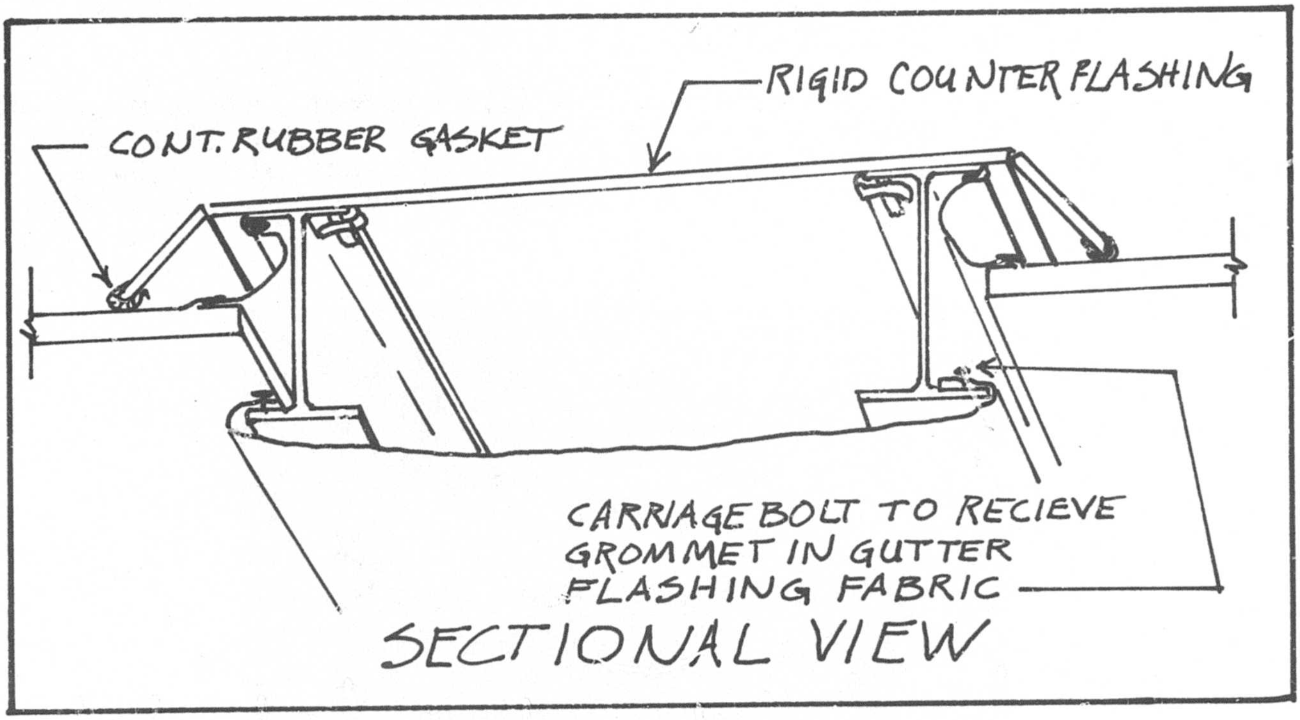


Figure 220. Counter Flashing Detail

Figure 221. Counter Flashing Installation

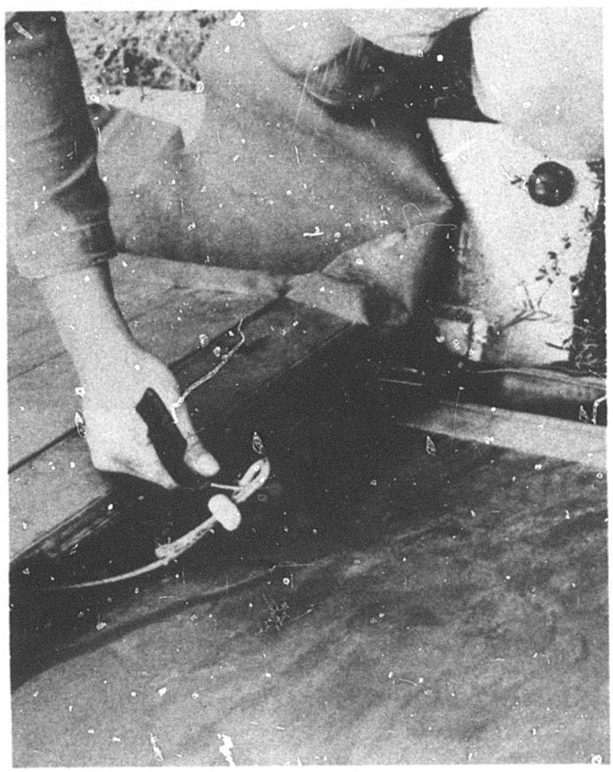


Figure 222. Counter Flashing Attachment to Base Pad

8. Side Personnel Door

Since the Openable Fabric End Wall did not have a personnel door, a side personnel door was provided. (Figure 223) The door unit was designed to be installed in place of any base arch panel and incorporates a standard 3' by 7' by 1-3/4" door and hardware.

Figure 223. Side Personnel Door

B. GENERAL PURPOSE SHELTER IMPROVEMENTS

Most components of the General Purpose Shelter are interchangeable with the Hangar. Improvements made on special components, both as reflected on the second prototype and as incorporated in refurbishing the first prototype, are discussed in the following paragraphs.

1. Knee Joint

The special strip used to flash panel to panel at the knee joint on the first prototype would tend to come apart in a gusty wind. This was caused by not having a solid back-up for the "Velcro" joint. This problem was remedied on the second prototype by making the downhill flashing on the first roof panel longer than on the standard panels. (Figure 224)

2. End Walls

The end walls remained basically the same as the first prototype. (Figure 225) The folding truck door is replaced with the sliding doors which are interchangeable with the Hangar doors. Also, special hard panels are added above the truck door and at each side of the end wall. This provided hard panel coverage of the full end wall.

C. FIELD TEST

The first and second hangar prototypes and the first and second general purpose shelter prototypes were erected at WPAFB during June and July, 1969. Modifications and repairs were made as required prior to packaging and shipment of these four shelters to Seymour-Johnson Air Force Base, Goldsboro, North Carolina. During August and September, 1969 these shelters were test-erected by the Air Force in preparation for the North Field, Coronet Bare exercise.

Representatives of the University of Cincinnati were authorized by the Air Mobility Office to make two trips to Seymour-Johnson AFB to monitor these test erections. Trips were made August 8 through 13 and September 25 through 29, 1969 for the purpose of getting a better understanding of forward air base operations, to assist in orientation of erection crews and in minor field repairs.

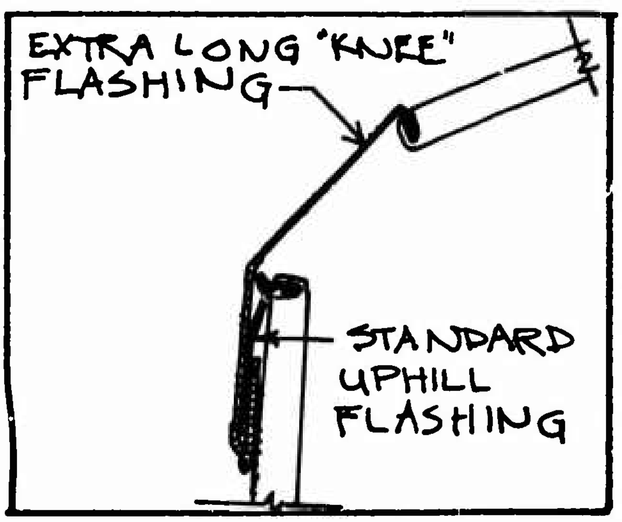


Figure 224. Knee Joint Panel Flashing

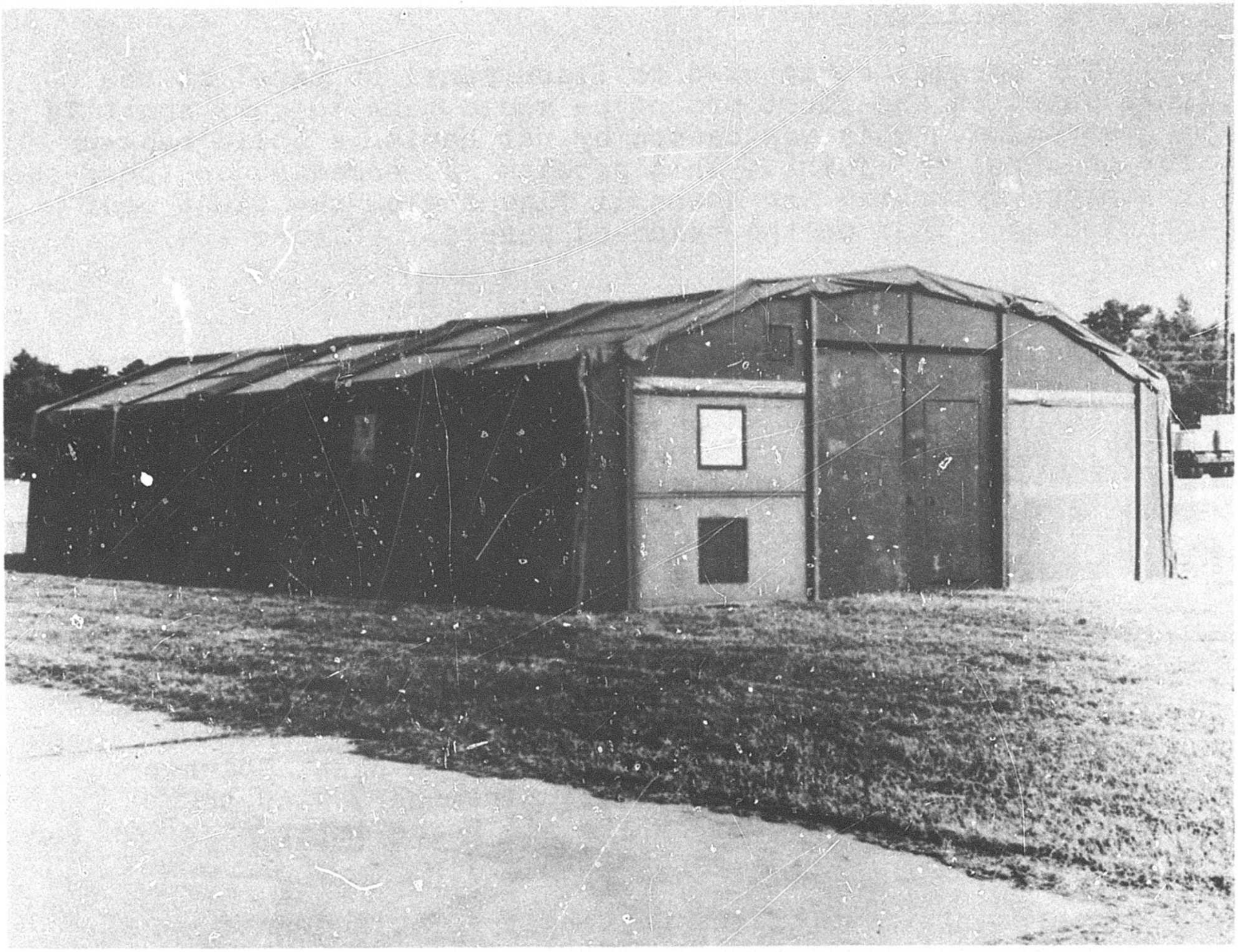


Figure 225. General Purpose Shelter

It was observed that Air Force erection crews could rather quickly understand the erection method, and once one shelter arch had been erected, their confidence increased and erection time for succeeding arches decreased.

Crew sizes were generally larger than recommended for unskilled crews. However this loss in erection time efficiency probably was best in this case in that more men could be trained for the follow-on Coronet Bare exercise.

Other observations made at the Seymour-Johnson exercise were:

1. Alternate light fixtures should be considered for achieving proper light intensity levels in critical maintenance and work areas.

2. A flooring system should be developed for use in

areas where clean air is required for critical maintenance.

3. A motor vehicle maintenance crew readily installed an exhaust ducting system in one of the hangars. If standard exhaust systems are employed by the Air Force, the Hangars could be easily modified to more efficiently receive these systems.

4. A General Purpose Shelter was used as a dining hall by adapting one of its end walls to connect to a kitchen facilities shelter. (Figure 226)

5. The hard counterflashing was found to be a real improvement over the all-fabric type.

From Seymour-Johnson AFB these shelters were deployed to North Field, South Carolina to take part in the Coronet Bare "bare base" demonstration. Since this demonstration was closed to contractors and the final report has not been released at the time of writing of this report, detailed evaluation of performance at North Field is not available at this time.

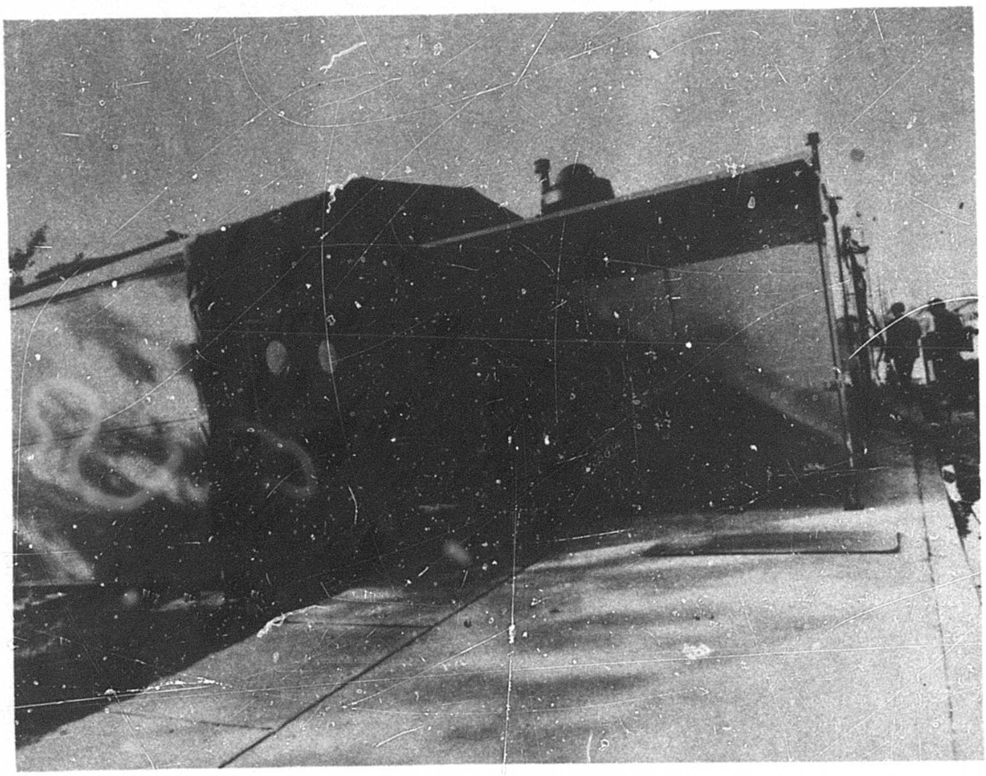


Figure 226. General Purpose Shelter with Kitchen Facility

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IX

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Conformance with Provisions of Contract

Concepts established for a portable aircraft hangar followed the program as outlined in the contract Statement of Work as modified by change orders and amendments. Major requirements of the contract include:

a. Development of new hangar concepts.

b. Fabrication of two hangar arch sections.

c. Fabrication of two full-size hangar prototypes.

d. Monitoring tests of hangar arch sections and full size shelters.

e. Working drawings of first hangar prototype.

f. Working drawings of second hangar prototype.

g. Modification kit drawings required to update the first hangar prototype to reflect improvements made in the second hangar prototype.

h. Refurbishment of the first hangar prototype to reflect improvements made in the second hangar prototype.

i. Effort to provide more "rugged" material for 16' x 32' shelter similar to those previously fabricated under contract AF33(615)1285.

j. Design and prototype section production of an F-111 aircraft size hangar (to be reported in a later volume of this report).

k. Work directed toward modification of composite materials for possible use in the personnel shelter developed by this contractor under contract F33615-67-C-1259. This work is being covered in the final report of that contract as authorized by SA/P018(70-1415) 17 November 69 of that contract.

l. The testing of 16' x 32' personnel shelters development under contract AF33(615)1285. This work was reported in Volume II of the final report of that contract. (AFAPL-TR-65-116, Volume II)

2. Shelter Conclusions

a. The concept of rapidly deployable, 100% recoverable aircraft hangars that are suitable for use on forward or bare base operational sites is an easily attainable goal.

b. Interchangeability of components between shelters of varying configuration provides practical advantages from manufacturing economies to the logistics of variable field use requirements.

c. In addition to shelter width variations, the shelter length can be changed easily by the addition or subtraction of arch sections.

d. This shelter system has the potential of serving other building needs such as auditorium, maintenance, recreational, warehousing, dining, etc. Of course, many of the varying needs would have different requirements with respect to floor covering, lighting requirements, air handling and ventilation.

e. Hard shelter components such as beams, columns, panels and base pads withstood repeated handling and erection cycles quite well and should last indefinitely with a minimum of maintenance required. Fabric flashing and end wall components did receive some wear and puncture damage. However, field repairs were accomplished with extra fabric and adhesives provided in the repair kit.

f. Primary problems encountered during field use were leakage due to wind blowing rain in at arch to arch counterflashing and condensation dripping from the panels in humid climates. Condensation was controlled from the arch beams with the use of the gutter flashing. However the panels would require a thermal barrier between outside and inside faces to inhibit condensation.

g. The shelters were easily erected by unskilled crews with a minimum of supervision. Crew confidence and proficiency increased rapidly as erection of the shelter progressed. It was observed that erection time in man-hours is markedly affected by the size of the erection crew. Generally, larger crews were more difficult to supervise, and resulting inefficiency caused wasted man-hours.

h. Two packaged shelters can be shipped on one C-130 aircraft. Near maximum cubage and weight limits of the aircraft are reached resulting in most efficient use of the aircraft capabilities.

B. RECOMMENDATIONS

1. Fabric end walls and flashing should be used for initial deployments and short term use. For extended on-site use,

more durable means of closure should be developed.

2. The counterflashing should be improved to provide positive weather sealing. Continuing design on the F-111 aircraft size hangar is developing a counterflashing which seals continuously to the panels.

3. A study should be performed to determine optimum erection crew sizes. Figure 227 shows the type of curve that is believed to be representative of the relationships between crew size and man-hours required for shelter erection. Some points on the curve are based upon unofficial reports of data collected at the Coronet Bare Exercise. However, more data is required to indicate a more accurate optimization of crew size. Also variables would have to be taken into account. Another method of increasing crew efficiency might be to provide a crew of 10 to 12 men with two erection gantries. This would be practical in a case where hangars are to be erected side by side on a flight line.

4. A flooring system should be developed to distribute concentrated loads where earth conditions are too soft and to provide a clean working area where required.

5. A variety of lighting kits should be provided to facilitate different lighting levels and requirements. Three kits should meet most requirements.

a. General lighting as provided in this work is adequate for warehouse use, and outlets provided would allow auxiliary portable lighting to serve infrequent critical work.

b. Maintenance and office type uses should have a lighting system that provides illumination of 30 to 40 foot candles.

c. Areas where explosive gases might accumulate should be provided with an explosion-proof lighting system.

6. The sandwich panels should be modified to incorporate a thermal barrier between inside and outside skins in order to cut down on moisture condensation on the inside face of the panels. This is difficult to do because in a thin structural panel the barrier material must not only contribute to the structural integrity of the panel it must also be an extremely effective thermal indicator.

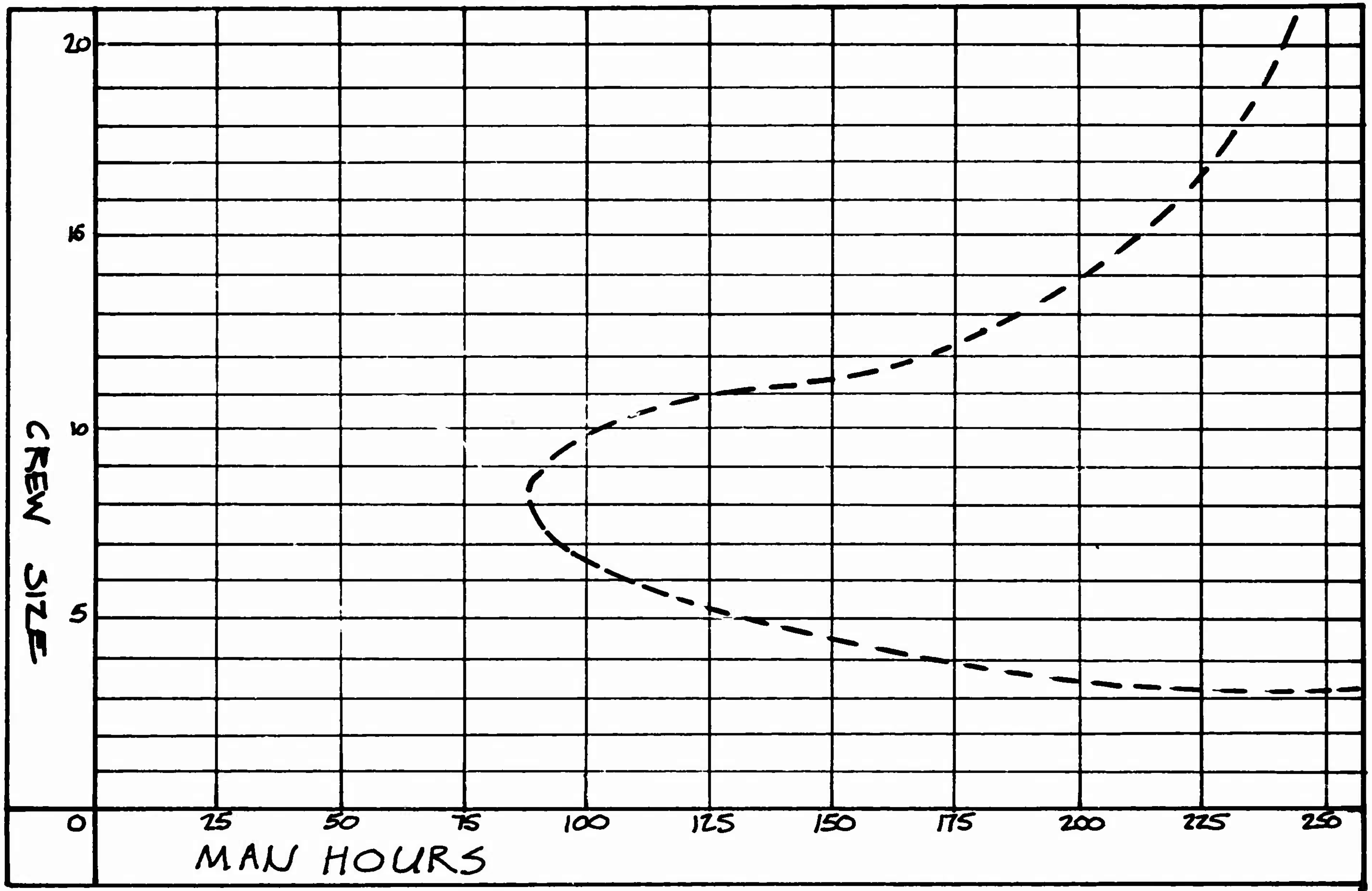

Figure 227. Crew Size Efficiency Curve

X

APPENDIXES

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APPENDIX A

ARCH RIB STRUCTURAL ANALYSIS

In this section, detailed computer program results of structural analysis of the hangar arch ribs are presented. The number designations indicated in the program are defined in Figure A-1.

The results are tabulated in the following manner:

Member	Length	I	A	M_a	M_b	F	V	M	F	V	M
n	ℓ	i	a	n	n + ℓ	f_t	q	f_b	f_t	q	f_b

Where n = member number designation
ℓ = length of member
i = moment of inertia of one arch rib
a = cross sectional area of one arch rib
n = joint designation number, start of the member
n + ℓ = joint designation number, end of the member
M_a = end A of the member and related information
M_b = end B of the member and related information
F = Axial load on one arch rib
V = Shear force across one arch rib
M = bending moment across one arch rib
f_t = maximum normal stress at top flange of the beam
f_b = maximum normal stress at bottom flange of the beam
q = maximum shear stress across beam = $\frac{VQ}{IT}$

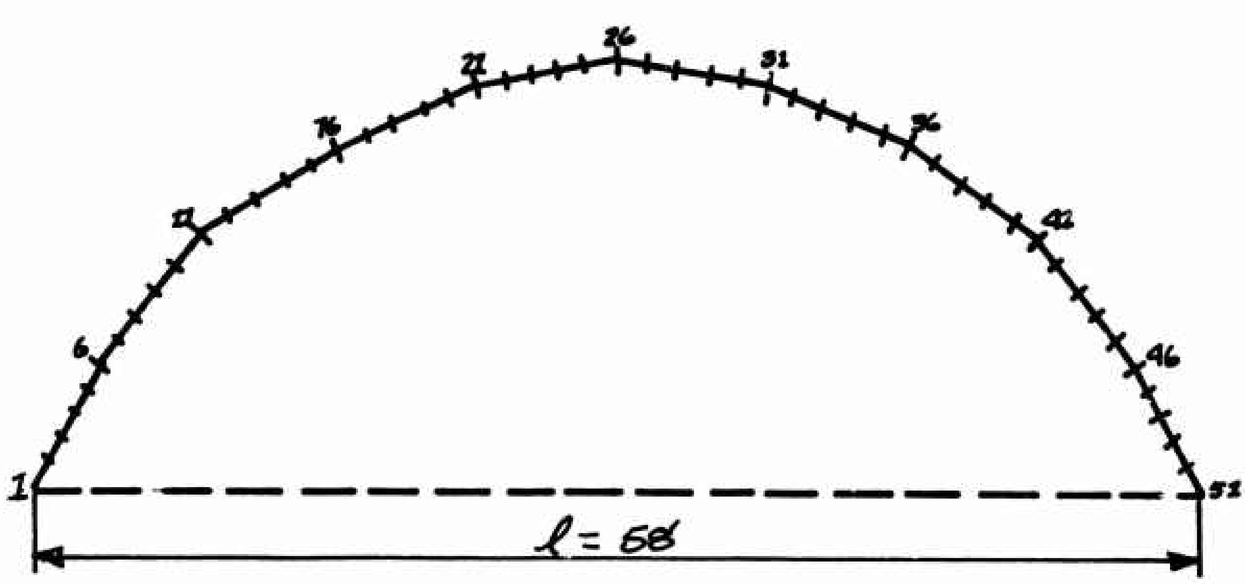

Figure A-1. Joint Designation

A. COMPUTER ANALYSIS

(i) 65 mph wind loading on structure
(ii) full snow load on structure, 20 lbs. per square foot

MEMBER	LENGTH	I	AREA	NA	NB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
1	11.32	13.370	2.632	1	2	-1.20843E 03	5.38563E 02	3.82813E-01	1.20843E 03	-5.38563E 02	6.09631E 03 (i)
						-4.59207E 02	5.12846E 02	-4.59050E 02	7.94788E 02	-5.12846E 02	-1.71304E 03
						4.15178E 03	-2.84807E 02	-1.00000E 00	-4.15178E 03	2.84807E 02	-3.22316E 03 (ii)
						1.57763E 03	-2.71207E 02	1.57722E 03	9.14470E 02	2.71207E 02	2.24038E 03
2	22.64	13.370	2.632	2	3	-1.20838E 03	4.97149E 02	-6.09596E 03	1.20838E 03	-4.97149E 02	1.73515E 04
						7.94731E 02	4.73410E 02	-1.71296E 03	3.10982E 03	-4.73410E 02	-4.02805E 03
						3.99126E 03	-3.64960E 02	3.22236E 03	-3.99126E 03	3.64960E 02	-1.14851E 04
						8.53646E 02	-3.47533E 02	2.17922E 03	-8.45877E 02	3.47533E 02	3.87879E 03
3	22.64	13.370	2.632	3	4	-1.20819E 03	4.55760E 02	-1.73517E 04	1.20819E 03	-4.55760E 02	2.76702E 04
						3.10994E 03	4.33998E 02	-4.02801E 03	5.23228E 03	-4.33998E 02	-6.15036E 03
						3.83095E 03	-4.45089E 02	1.14858E 04	-3.83095E 03	4.45089E 02	-2.15627E 04
						-9.06930E 02	-4.23836E 02	3.81799E 03	-2.97959E 03	4.23836E 02	5.89065E 03
4	22.64	13.370	2.632	4	5	-1.20827E 03	4.14468E 02	-2.76694E 04	1.20827E 03	-4.14468E 02	3.70531E 04
						5.23210E 03	3.94677E 02	-6.15023E 03	7.16217E 03	-3.94677E 02	-8.08031E 03
						3.67051E 03	-5.25479E 02	2.15613E 04	-3.67051E 03	5.25479E 02	-3.34582E 04
						-3.04025E 03	-5.00387E 02	5.82939E 03	-5.48727E 03	5.00387E 02	8.27640E 03
5	11.32	13.370	2.632	5	6	-1.20859E 03	3.73441E 02	-3.70502E 04	1.20859E 03	-3.73441E 02	4.12779E 04
						7.16146E 03	3.55609E 02	-8.07985E 03	8.03103E 03	-3.55609E 02	-8.94941E 03
						3.51106E 03	-6.06350E 02	3.34524E 04	-3.51106E 03	6.06350E 02	-4.03159E 04
						-5.54665E 03	-5.77396E 02	-8.21463E 03	-6.95835E 03	5.77396E 02	[illegible] 03
6	11.34	13.370	2.632	6	7	-1.26275E 03	5.12832E 01	-4.12786E 04	1.26275E 03	-5.12832E 01	4.18602E 04
						8.01060E 03	4.88344E 01	-8.97014E 03	8.13021E 03	-4.88344E 01	[illegible] 03
						3.54755E 03	3.13094E 02	4.03161E 04	-3.54755E 03	-3.13094E 02	-3.67642E 04
						-6.94453E 03	2.98144E 02	9.64024E 03	-6.21398E 03	-2.98144E 02	8.90968E 03
7	22.69	13.370	2.632	7	8	-1.26387E 03	1.04058E 01	-4.18631E 04	1.26387E 03	-1.04058E 01	4.20992E 04
						8.13038E 03	9.90888E 00	-9.09077E 03	8.17895E 03	-9.90888E 00	-9.13934E 03
						3.41375E 03	1.93634E 02	3.67697E 04	-3.41375E 03	-1.93634E 02	-3.23760E 04
						-6.26593E 03	1.84388E 02	-8.85996E 03	-5.36222E 03	-1.84388E 02	[illegible] 03
8	22.69	13.370	2.632	8	9	-1.26294E 03	-3.09521E 01	-4.20990E 04	1.26294E 03	3.09521E 01	4.13967E 04
						8.17927E 03	-2.94742E 01	-9.13895E 03	8.03482E 03	2.94742E 01	-8.99450E 03
						3.27830E 03	7.46293E 01	3.23761E 04	-3.27830E 03	-7.46293E 01	-3.06828E 04
						-5.41371E 03	7.10657E 01	7.90482E 03	-5.06541E 03	-7.10657E 01	7.55652E 03
9	22.69	13.370	2.632	9	10	-1.26298E 03	-7.23420E 01	-4.13963E 04	1.26298E 03	7.23420E 01	3.97548E 04
						8.03471E 03	-6.88877E 01	-8.99442E 03	7.69708E 03	6.88877E 01	-8.65679E 03
						3.14310E 03	-4.39502E 01	3.06820E 04	-3.14310E 03	4.39502E 01	-3.16793E 04
						-5.11662E 03	-4.18516E 01	7.50500E 03	-5.32174E 03	4.18516E 01	7.71011E 03
10	11.35	13.370	2.632	10	11	-1.26441E 03	-1.13418E 02	-3.97541E 04	1.26441E 03	1.13418E 02	3.84667E 04
						7.69640E 03	-1.08002E 02	-8.65719E 03	7.43160E 03	1.08002E 02	-8.39240E 03
						3.01162E 03	-1.63471E 02	3.16766E 04	-3.01162E 03	1.63471E 02	-3.35314E 04
						-5.37114E 03	-1.55665E 02	7.65961E 03	-5.75264E 03	1.55665E 02	8.04111E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
11	11.36	13.370	2.632	11	12	-1.19687E 03	-4.19746E 02	-3.84642E 04	1.19687E 03	4.19746E 02	3.36945E 04
						7.45675E 03	-3.99703E 02	-8.36623E 03	6.47570E 03	3.99703E 02	-7.38517E 03
						2.95554E 03	5.80395E 02	3.35255E 04	-2.95554E 03	-5.80395E 02	-2.69307E 04
						-5.77274E 03	5.52681E 02	8.01859E 03	-4.41630E 03	$\boxed{-5.52681E\ 02}$	6.46215E 03
12	22.73	13.370	2.632	12	13	-1.19777E 03	-3.34532E 02	-3.36934E 04	1.19777E 03	3.34532E 02	2.60906E 04
						6.47513E 03	-3.18558E 02	-7.38528E 03	4.91135E 03	3.18558E 02	-5.82150E 03
						2.85724E 03	4.32349E 02	2.69288E 04	-2.85724E 03	-4.32349E 02	-1.71030E 04
						-4.45326E 03	4.11704E 02	6.62441E 03	-2.43224E 03	-4.11704E 02	4.40339E 03
13	22.73	13.370	2.632	13	14	-1.19705E 03	-2.48978E 02	-2.60907E 04	1.19705E 03	2.48978E 02	2.04325E 04
						4.91164E 03	-2.37089E 02	-5.82125E 03	3.74784E 03	2.37089E 02	-4.65745E 03
						2.75387E 03	2.83904E 02	1.71034E 04	-2.75387E 03	-2.83904E 02	-1.06514E 04
						-2.47161E 03	2.70348E 02	4.56421E 03	-1.14452E 03	-2.70348E 02	3.23713E 03
14	22.73	13.370	2.632	14	15	-1.19720E 03	-1.63450E 02	-2.04319E 04	1.19720E 03	1.63450E 02	1.67173E 04
						3.74766E 03	-1.55646E 02	-4.65739E 03	2.98362E 03	1.55646E 02	-3.89334E 03
						2.65230E 03	1.35354E 02	1.06506E 04	-2.65230E 03	-1.35354E 02	-7.57440E 03
						-1.18294E 03	1.28891E 02	3.19836E 03	-5.50224E 02	-1.28891E 02	2.56565E 03
15	11.36	13.370	2.632	15	16	-1.19678E 03	-7.80596E 01	-1.67175E 04	1.19678E 03	7.80596E 01	1.58307E 04
						2.98383E 03	-7.43322E 01	-3.89324E 03	2.80143E 03	7.43322E 01	-3.71084E 03
						2.54913E 03	-1.22324E 01	7.57782E 03	-2.54913E 03	1.22324E 01	-7.71680E 03
						-5.90124E 02	-1.16483E 01	2.52715E 03	-6.18709E 02	1.16483E 01	2.55574E 03
16	11.27	13.370	2.632	16	17	-1.14794E 03	-3.47947E 02	-1.58306E 04	1.14794E 03	3.47947E 02	1.19106E 04
						2.81997E 03	-3.31333E 02	-3.69226E 03	2.01367E 03	3.31333E 02	-2.88597E 03
						2.48715E 03	5.67312E 02	7.72117E 03	-2.48715E 03	-5.67312E 02	-1.32916E 03
						-6.43159E 02	5.40223E 02	2.53309E 03	6.71979E 02	-5.40223E 02	1.21835E 03
17	22.54	13.370	2.632	17	18	-1.14753E 03	-2.62436E 02	-1.19103E 04	1.14753E 03	2.62436E 02	5.99629E 03
						2.01377E 03	-2.49905E 02	-2.88575E 03	7.97352E 02	2.49905E 02	-1.66934E 03
						2.42105E 03	4.00899E 02	1.32928E 03	-2.42105E 03	-4.00899E 02	7.70497E 03
						6.46441E 02	3.81756E 02	1.19327E 03	2.50465E 03	-3.81756E 02	-6.64939E 02
18	22.54	13.370	2.632	18	19	-1.14817E 03	-1.76874E 02	-5.99626E 03	1.14817E 03	1.76874E 02	2.01030E 03
						7.97103E 02	-1.68428E 02	-1.66957E 03	-2.27466E 01	1.68428E 02	-8.49721E 02
						2.35772E 03	2.34634E 02	-7.70537E 03	-2.35772E 03	-2.34634E 02	1.29929E 04
						2.48066E 03	2.23430E 02	-6.89083E 02	3.56822E 03	-2.23430E 02	-1.77664E 03
19	22.54	13.370	2.632	19	20	-1.14861E 03	-9.13496E 01	-2.01023E 03	1.14861E 03	9.13496E 01	-4.82969E 01
						-2.29296E 01	-8.69876E 01	-8.49874E 02	-4.46336E 02	8.69876E 01	-4.26460E 02
						2.29320E 03	6.84507E 01	-1.29929E 04	-2.29320E 03	-6.84507E 01	1.45355E 04
						3.54372E 03	6.51821E 01	-1.80116E 03	3.86100E 03	-6.51821E 01	-2.11844E 03
20	11.27	13.370	2.632	20	21	-1.14754E 03	-5.64355E 00	4.92149E 01	1.14754E 03	5.64355E 00	-1.12945E 02
						-4.40117E 02	-5.37407E 00	-4.25871E 02	-4.59225E 02	5.37407E 00	-4.12763E 02
						2.22658E 03	-9.77617E 01	-1.45350E 04	-2.22658E 03	9.77617E 01	1.34329E 04
						3.83559E 03	-9.30936E 01	-2.14367E 03	3.60891E 03	9.30936E 01	-1.91698E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
21	11.33	13.370	2.632	21	22	-1.11028E 03	-2.95578E 02	1.13145E 02	1.11028E 03	2.95578E 02	-3.46090E 03
						-4.45113E 02	-2.81464E 02	-3.98568E 02	-1.13369E 03	2.81464E 02	2.90012E 02
						2.18093E 03	4.68248E 02	-1.34301E 04	-2.18093E 03	-4.68248E 02	1.87337E 04
						3.59098E 03	$\boxed{4.45889E\ 02}$	-1.93374E 03	4.68185E 03	-4.45889E 02	-3.02461E 03
22	22.65	13.370	2.632	22	23	-1.10980E 03	-2.09922E 02	3.45979E 03	1.10980E 03	2.09922E 02	-8.21510E 03
						-1.13328E 03	-1.99898E 02	2.89969E 02	-2.11137E 03	1.99898E 02	1.26806E 03
						2.16016E 03	2.89531E 02	-1.87311E 04	-2.16016E 03	-2.89531E 02	2.52897E 04
						4.67342E 03	2.75706E 02	-3.03196E 03	6.02243E 03	-2.75706E 02	-4.38097E 03
23	22.65	13.370	2.632	23	24	-1.11000E 03	-1.24436E 02	8.21432E 03	1.11000E 03	1.24436E 02	-1.10331E 04
						-2.11129E 03	-1.18494E 02	1.26782E 03	-2.64107E 03	1.18494E 02	1.84760E 03
						2.13930E 03	1.11481E 02	-2.52891E 04	-2.13930E 03	-1.11481E 02	2.78145E 04
						6.01439E 03	1.06158E 02	-4.38877E 03	6.53381E 03	-1.06158E 02	-4.90820E 03
24	22.65	13.370	2.632	24	25	-1.10991E 03	-3.88638E 01	1.10330E 04	1.10991E 03	3.88638E 01	-1.19133E 04
						-2.69102E 03	-3.70080E 01	1.84763E 03	-2.87208E 03	3.70080E 01	2.02869E 03
						2.11843E 03	-6.67380E 01	-2.78143E 04	-2.11843E 03	6.67380E 01	2.63026E 04
						6.52584E 03	-6.35512E 01	-4.91609E 03	6.21491E 03	6.35512E 01	-4.60516E 03
25	11.33	13.370	2.632	25	26	-1.10930E 03	4.66367E 01	1.19138E 04	1.10930E 03	-4.66367E 01	-1.13854E 04
						-2.87196E 03	4.44098E 01	2.02903E 03	-2.76327E 03	-4.44098E 01	1.92034E 03
						2.09667E 03	-2.44756E 02	-2.63025E 04	-2.09667E 03	2.44756E 02	2.35303E 04
						6.20662E 03	-2.33069E 02	-4.61340E 03	5.63642E 03	2.33069E 02	-4.04321E 03
26	11.33	13.370	2.632	26	27	-1.09107E 03	-2.10363E 02	1.13848E 04	1.09107E 03	2.10363E 02	-1.37678E 04
						-2.75622E 03	-2.00318E 02	1.92713E 03	-3.24636E 03	2.00318E 02	2.41728E 03
						2.09778E 03	2.45042E 02	-2.35283E 04	-2.09778E 03	-2.45042E 02	2.63043E 04
						5.83844E 03	2.33341E 02	-4.04238E 03	6.20741E 03	-2.33341E 02	-4.61336E 03
27	22.65	13.370	2.632	27	28	-1.09074E 03	-1.24688E 02	1.37673E 04	1.09074E 03	1.24688E 02	-1.65918E 04
						-3.24613E 03	-1.18734E 02	2.41730E 03	-3.82709E 03	1.18734E 02	2.99827E 03
						2.11804E 03	6.66299E 01	-2.63032E 04	-2.11804E 03	-6.66299E 01	2.78125E 04
						6.21489E 03	6.34483E 01	-4.60544E 03	6.52533E 03	-6.34483E 01	-4.91588E 03
28	22.65	13.370	2.632	28	29	-1.09072E 03	-3.91902E 01	1.65921E 04	1.09072E 03	3.91902E 01	-1.74798E 04
						-3.82713E 03	-3.73188E 01	2.99832E 03	-4.00972E 03	3.73188E 01	3.18091E 03
						2.13868E 03	-1.11520E 02	-2.78128E 04	-2.13868E 03	1.11520E 02	2.52864E 04
						6.53372E 03	-1.06195E 02	-4.90808E 03	6.01359E 03	1.06195E 02	-4.38846E 03
29	22.65	13.370	2.632	29	30	-1.09090E 03	4.62677E 01	1.74797E 04	1.09090E 03	-4.62677E 01	-1.64315E 04
						-4.00978E 03	4.40584E 01	3.18082E 03	-3.79419E 03	-4.40584E 01	2.96524E 03
						2.15981E 03	-2.89589E 02	-2.52865E 04	-2.15981E 03	2.89589E 02	1.87267E 04
						6.02164E 03	-2.75761E 02	-4.38044E 03	4.67238E 03	2.75761E 02	-3.03119E 03
30	11.33	13.370	2.632	30	31	-1.09068E 03	1.31691E 02	1.64310E 04	1.09068E 03	-1.31691E 02	-1.49394E 04
						-3.79400E 03	1.25403E 02	2.96522E 03	-3.48720E 03	-1.25403E 02	-2.65841E 03
						2.17938E 03	-4.67794E 02	-1.87267E 04	-2.17938E 03	4.67794E 02	1.34282E 04
						4.67982E 03	-4.45457E 02	-3.02376E 03	3.59001E 03	4.45457E 02	-1.93394E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
31	11.27	13.370	2.632	31	32	-1.08866E 03	-1.48226E 02	1.49382E 04	1.08866E 03	1.48226E 02	-1.66083E 04
						-3.48618E 03	-1.41148E 02	2.65894E 03	-3.82969E 03	1.41148E 02	3.00245E 03
						2.22773E 03	9.82187E 01	-1.34270E 04	-2.22773E 03	-9.82187E 01	1.45334E 04
						3.60812E 03	9.35288E 01	-1.91531E 03	3.83574E 03	-9.35288E 01	-2.14293E 03
32	22.54	13.370	2.632	32	33	-1.08897E 03	-6.24390E 01	1.66072E 04	1.08897E 03	6.24390E 01	-1.80144E 04
						-3.82959E 03	-5.94576E 01	3.00211E 03	-4.11901E 03	5.94576E 01	3.29153E 03
						2.29287E 03	-6.84490E 01	-1.45322E 04	-2.29287E 03	6.84490E 01	1.29896E 04
						3.86019E 03	-6.51805E 01	-2.11788E 03	3.54292E 03	6.51805E 01	-1.80061E 03
33	22.54	13.370	2.632	33	34	-1.08822E 03	2.30151E 01	1.80145E 04	1.08822E 03	-2.30151E 01	-1.74958E 04
						-4.11876E 03	2.19161E 01	3.29184E 03	-4.01206E 03	-2.19161E 01	3.18515E 03
						2.35648E 03	-2.34735E 02	-1.29905E 04	-2.35668E 03	2.34735E 02	7.70076E 03
						3.56734E 03	-2.23527E 02	-1.77656E 03	2.47932E 03	2.23527E 02	-6.88533E 02
34	22.54	13.370	2.632	34	35	-1.08928E 03	1.08449E 02	1.74957E 04	1.08926E 03	-1.08449E 02	-1.50517E 04
						-4.01244E 03	1.03270E 02	3.18472E 03	-3.50976E 03	-1.03270E 02	2.68204E 03
						2.42219E 03	-4.00864E 02	-7.70085E 03	-2.42219E 03	4.00864E 02	-1.33261F 03
						2.50423E 03	-3.81722E 02	-6.63658E 02	6.46188E 02	3.81722E 02	1.19438E 03
35	11.27	13.370	2.632	35	36	-1.08855E 03	1.94112E 02	1.50521E 04	1.08855E 03	-1.94112E 02	-1.28651E 04
						-3.50955E 03	1.84843E 02	2.68239E 03	-3.05974E 03	-1.84843E 02	2.23258E 03
						2.48570E 03	-5.67691E 02	1.33064E 03	-2.48530E 03	5.67691E 02	-7.72701E 03
						6.70574E 02	-5.40584E 02	1.21796E 03	-6.45060E 02	5.40584E 02	2.53359E 03
36	11.36	13.370	2.632	36	37	-1.10444E 03	-5.87202E 01	1.28660E 04	1.10444E 03	5.87202E 01	-1.35332E 04
						-3.06595E 03	-5.59163E 01	2.22671E 03	-3.20319E 03	5.59163E 01	2.36395E 03
						2.55081E 03	1.29746E 01	7.72479E 03	-2.55081E 03	-1.29746F 01	-7.57734E 03
						-6.19715E 02	1.23551E 01	2.55802E 03	-5.89387E 02	-1.23551E 01	2.52769E 03
37	22.73	13.370	2.632	37	38	-1.10423E 03	2.67131E 01	1.35336E 04	1.10423E 03	-2.67131E 01	-1.29265E 04
						-3.20319E 03	2.54376E 01	2.36410E 03	-3.07831E 03	-2.54376E 01	2.23923E 03
						2.65164E 03	-1.35426E 02	7.57728E 03	-2.65164E 03	1.35426E 02	-1.06551E 04
						-5.51065E 02	-1.28960E 02	2.56599E 03	-1.18412E 03	1.28960E 02	3.19905E 03
38	22.73	13.370	2.632	38	39	-1.10459E 03	1.12196E 02	1.29263E 04	1.10459E 03	-1.12196E 02	-1.03765E 04
						-3.07842E 03	1.06838E 02	2.23907E 03	-2.55396E 03	-1.06838E 02	1.71460E 03
						2.75400E 03	-2.84000E 02	1.06541E 04	-2.75400E 03	2.84000E 02	-1.71083E 04
						-1.14503E 03	-2.70439E 02	3.23773E 03	-2.47256E 03	2.70439E 02	4.56526E 03
39	22.73	13.370	2.632	39	40	-1.10432E 03	1.97636E 02	1.03760E 04	1.10432E 03	-1.97636E 02	-5.88448E 03
						-2.55377E 03	1.88199E 02	1.71462E 03	-1.62992E 03	-1.88199E 02	7.90771E 02
						2.85548E 03	-4.32258E 02	1.71080E 04	-2.85548E 03	4.32258E 02	-2.69318E 04
						-2.43394E 03	-4.11618E 02	4.60376E 03	-4.45455E 03	4.11618E 02	6.62437E 03
40	11.36	13.370	2.632	40	41	-1.10408E 03	2.83383E 02	5.88561E 03	1.10408E 03	-2.83383E 02	-2.66535E 03
						-1.63006E 03	2.69851E 02	7.91094E 02	-9.67704E 02	-2.69851E 02	1.28739E 02
						2.95654E 03	-5.81134E 02	2.69305E 04	-2.95654E 03	5.81134E 02	-3.35341E 04
						-4.41588E 03	-5.53384E 02	6.66249E 03	-5.77413E 03	5.53384E 02	8.02074E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXI L FORCE	SHEAR	MCMENT	AXIAL FORCE	SHEAR	MOMENT
41	11.35	13.370	2.632	41	42	-1.14050E 03	2.97656E 00	2.66555E 03	1.14050E 03	-2.97656E 00	-2.63191E 03
						-9.81582E 02	2.83443E 00	1.14941E 02	-9.74663E 02	-2.83443E 00	1.08021E 02
						3.00983E 03	1.62588E 02	3.35308E 04	-3.00983E 03	-1.62588E 02	-3.16862E 04
						-5.75321E 03	1.54824E 02	8.04031E 03	-5.37379E 03	-1.54824E 02	7.66090E 03
42	22.69	13.370	2.632	42	43	-1.14010E 03	4.31899E 01	2.63069E 03	1.14010E 03	-4.31899E 01	-1.65068E 03
						-9.74262E 02	4.11276E 01	1.07923E 02	-7.72687E 02	-4.11276E 01	-9.36511E 01
						3.14402E 03	4.40322E 01	3.16845E 04	-3.14402E 03	-4.40322E 01	-3.06853E 04
						-5.32246E 03	4.19297E 01	7.71153E 03	-5.11695E 03	-4.19297E 01	7.50603E 03
43	22.69	13.370	2.632	43	44	-1.14027E 03	8.31526E 01	1.65027E 03	1.14027E 03	-8.31526E 01	2.36449E 02
						-7.72670E 02	7.91820E 01	-9.37995E 01	-3.84601E 02	-7.91820E 01	-4.81868E 02
						3.27884E 03	-7.47087E 01	3.06854E 04	-3.27884E 03	7.47087E 01	-3.23805E 04
						-5.06574E 03	-7.11413E 01	7.55726E 03	-5.41442E 03	7.11413E 01	7.90593E 03
44	22.69	13.370	2.632	44	45	-1.14012E 03	1.23222E 02	-2.36592E 02	1.14012E 03	-1.23222E 02	3.03243E 03
						-3.84512E 02	1.17338E 02	-4.81838E 02	1.90547E 02	-1.17338E 02	-1.05690E 03
						3.41359E 03	-1.93621E 02	3.23803E 04	-3.41359E 03	1.93621E 02	-3.67734E 04
						-5.36316E 03	-1.84376E 02	7.95708E 03	-6.26679E 03	1.84376E 02	8.86071E 03
45	11.35	13.370	2.632	45	46	-1.14017E 03	1.63087E 02	-3.03215E 03	1.14017E 03	-1.63087E 02	4.88253E 03
						1.90471E 02	1.55299E 02	-1.05686E 03	5.71064E 02	-1.55299E 02	-1.43746E 03
						3.54886E 03	-3.12075E 02	3.67739E 04	-3.54886E 03	3.12075E 02	-4.03143E 04
						-6.21547E 03	-2.97174E 02	8.91217E 03	-6.94373E 03	2.97174E 02	$\boxed{9.64043E\ 03}$
46	11.32	13.370	2.632	46	47	-1.14393E 03	-1.33965E 02	-4.88241E 03	1.14393E 03	1.33965E 02	3.36611E 03
						5.69611E 02	-1.27568E 02	-1.43886E 03	2.57732E 02	1.27568E 02	-1.12698E 03
						3.51052E 03	6.05560E 02	4.03149E 04	-3.51052E 03	-6.05560E 02	[illegible]
						-6.99877E 03	5.76644E 02	[illegible]	-5.54843E 03	-5.76644E 02	8.21599E 03
47	22.64	13.370	2.632	47	48	-1.14398E 03	-9.39324E 01	-3.36643E 03	1.14398E 03	9.39324E 01	1.23973E 03
						2.57778E 02	-8.94471E 01	-1.12706E 03	-1.79650E 02	8.94471E 01	-6.89636E 02
						3.67058E 03	5.25333E 02	3.34594E 04	-3.67058E 03	-5.25333E 02	-2.15658E 04
						-5.48748E 03	5.00248E 02	8.27667E 03	-3.04115E 03	-5.00248E 02	5.83034E 03
48	22.64	13.370	2.632	48	49	-1.14391E 03	-5.39053E 01	-1.23991E 03	1.14391E 03	5.39053E 01	1.95000E 01
						-1.79587E 02	-5.13313E 01	-6.89647E 02	-4.30606E 02	5.13313E 01	-4.38628E 02
						3.83102E 03	4.45151E 02	2.15654E 04	-3.83102E 03	-4.45151E 02	-1.14870E 04
						-2.98011E 03	4.23895E 02	5.89122E 03	-9.07151E 02	-4.23895E 02	3.81826E 03
49	22.64	13.370	2.632	49	50	-1.14389E 03	-1.39160E 01	-1.93730E 01	1.14389E 03	1.39160E 01	-2.95664E 02
						-4.30625E 02	-1.32515E 01	-4.38594E 02	-4.95427E 02	1.32515E 01	-3.75792E 02
						3.99141E 03	3.65012E 02	1.14867E 04	-3.99141E 03	-3.65012E 02	-3.22279E 03
						-8.43144E 02	3.47583E 02	3.87913E 03	8.53628E 02	-3.47583E 02	2.17936E 03
50	11.32	13.370	2.632	50	51	-1.14392E 03	2.61289E 01	2.95785E 02	1.14392E 03	-2.61289E 01	3.12500E-02
						-4.95458E 02	2.48812E 01	-3.73781E 02	-4.34613E 02	-2.48812E 01	-4.34626E 02
						4.15172E 03	2.84629E 02	3.22248E 03	-4.15172E 03	-2.84629E 02	-3.43750E-01
						9.14590E 02	2.71038E 02	2.24027E 03	1.57733E 03	-2.71038E 02	1.57747E 03

1.6

JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
1	-349.500	0.	0.	0.	0.	0.	0.	-4.2706E-02
			0.	0.	-0.	0.	0.	2.3695E-02
2	-344.437	10.125	37.029	-18.515	0.	4.3176E-01	-2.1532E-01	-4.2440E-02
			-0.	-179.235	-0.	-2.4025E-01	1.1814E-01	2.3559E-02
3	-334.312	30.375	37.029	-18.515	0.	1.2749E 00	-6.3574E-01	-4.0463E-02
			-0.	-179.235	-0.	-7.0860E-01	3.4848E-01	2.2313E-02
4	-324.187	50.625	37.029	-18.515	0.	2.0591E 00	-1.0267E 00	-3.6651E-02
			-0.	-179.235	-0.	-1.1365E 00	5.5873E-01	1.9515E-02
5	-314.062	70.875	37.029	-18.515	0.	2.7490E 00	-1.3704E 00	-3.1171E-02
			-0.	-179.235	-0.	-1.4893E 00	7.3161E-01	1.4857E-02
6	-309.000	81.000	0.	0.	0.	3.0483E 00	-1.5195E 00	-2.7855E-02
			-0.	-0.	-0.	-1.6251E 00	7.9781E-01	1.1734E-02
7	-301.500	89.512	31.063	-27.368	0.	3.2708E 00	-1.7148E 00	-2.4328E-02
			-0.	-179.632	-0.	-1.7118E 00	8.7222E-01	8.4638E-03
8	-286.500	106.537	31.063	-27.368	0.	3.6251E 00	-2.0255E 00	-1.7203E-02
			-0.	-179.632	-0.	-1.8069E 00	9.5203E-01	2.5964E-03
9	-271.500	123.562	31.063	-27.368	0.	3.8583E 00	-2.2295E 00	-1.0118E-02
			-0.	-179.632	-0.	$\boxed{-1.8070E\ 00}$	9.4836E-01	-2.7544E-03
10	-256.500	140.587	31.063	-27.368	0.	3.9722E 00	-2.3285E 00	-3.2323E-03
			-0.	-179.632	-0.	-1.7171E 00	8.6554E-01	-8.0461E-03
11	-249.000	149.100	0.	0.	0.	$\boxed{3.9859E\ 00}$	$\boxed{-2.3398E\ 00}$	8.6546E-05
			-0.	-0.	-0.	-1.6378E 00	7.9394E-01	-1.0813E-02
12	-239.625	155.521	-48.315	70.540	0.	3.9757E 00	-2.3240E 00	3.1529E-03
			-0.	-179.918	-0.	-1.5609E 00	6.7937E-01	-1.3382E-02
13	-220.875	168.364	-48.315	70.540	0.	3.9021E 00	-2.2146E 00	8.2341E-03
			-0.	-179.918	-0.	-1.3652E 00	3.8937E-01	-1.7124E-02
14	-202.125	181.206	-48.315	70.540	0.	3.7707E 00	-2.0211E 00	1.2188E-02
			-0.	-179.918	-0.	-1.1309E 00	4.3117E-02	-1.9483E-02
15	-183.375	194.049	-48.315	70.540	0.	3.5941E 00	-1.7614E 00	1.5345E-02
			-0.	-179.918	-0.	-8.7211E-01	-3.3882E-01	-2.1032E-02
16	-174.000	200.470	0.	0.	0.	3.4915E 00	-1.6107E 00	1.6729E-02
			-0.	-0.	-0.	-7.3589E-01	-5.3966E-01	-2.1682E-02

JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
17	-163.500	204.557	-31.017	79.676	0.	3.4211E 00	-1.4284E 00	1.7897E-02
			-0.	-178.403	-0.	-6.4730E-01	-7.7018E-01	-2.2063E-02
18	-142.500	212.732	-31.017	79.676	0.	3.2689E 00	-1.0346E 00	1.9407E-02
			-0.	-178.403	-0.	-4.7002E-01	-1.2313E 00	-2.1526E-02
19	-121.500	220.907	-31.017	79.676	0.	3.1079E 00	-6.1849E-01	2.0081E-02
			-0.	-178.403	-0.	-3.0245E-01	-1.6673E 00	-1.9782E-02
20	-100.500	229.082	-31.017	79.676	0.	2.9438E 00	-1.9408E-01	2.0247E-02
			-0.	-178.403	-0.	-1.5187E-01	-2.0595E 00	-1.7462E-02
21	-90.000	233.170	0.	0.	0.	2.8615E 00	1.8652E-02	2.0240E-02
			-0.	-0.	-0.	-8.3817E-02	-2.2370E 00	-1.6283E-02
22	-78.750	234.482	-9.908	84.924	0.	2.8355E 00	2.4582E-01	2.0080E-02
			-0.	-179.333	-0.	-6.4230E-02	-2.4130E 00	-1.4921E-02
23	-56.250	237.107	-9.908	84.924	0.	2.7848E 00	6.8830E-01	1.9099E-02
			-0.	-179.333	-0.	-3.1561E-02	-2.7091E 00	-1.1192E-02
24	-33.750	239.732	-9.908	84.924	0.	2.7376E 00	1.1007E 00	1.7469E-02
			-0.	-179.333	-0.	-9.8227E-03	-2.9113E 00	-6.6931E-03
25	-11.250	242.357	-9.908	84.924	0.	2.6953E 00	1.4723E 00	1.9529E-02
			-0.	-179.333	-0.	-1.3755E-04	-3.0100E 00	-2.1006E-03
26	0.	243.670	0.	0.	0.	2.6760E 00	1.6414E 00	1.4538E-02
			-0.	-0.	-0.	3.2342E-04	$\boxed{-3.0218E\ 00}$	2.1929E-06
27	11.250	242.357	9.908	84.924	0.	2.6949E 00	1.7991E 00	1.3473E-02
			-0.	-179.333	-0.	7.8965E-04	-3.0100E 00	2.1130E-03
28	33.750	239.732	9.908	84.924	0.	2.7279E 00	2.0741E 00	1.0901E-02
			-0.	-179.333	-0.	1.0487E-02	-2.9111E 00	6.6974E-03
29	56.250	237.107	9.908	84.924	0.	2.7537E 00	2.2870E 00	8.0144E-03
			-0.	-179.333	-0.	3.2237E-02	-2.7088E 00	1.1196E-02
30	78.750	234.482	9.908	84.924	0.	2.7719E 00	2.4346E 00	5.1417E-03
			-0.	-179.333	-0.	6.4915E-02	-2.4127E 00	1.4924E-02
31	90.000	233.170	0.	0.	0.	2.7782E 00	2.4848E 00	3.8129E-03
			-0.	-0.	-0.	8.4507E-02	-2.2366E 00	1.6286E-02
32	100.500	229.082	31.017	79.676	0.	2.7915E 00	2.5178E 00	2.4836E-03
			-0.	-178.403	-0.	1.5257E-01	-2.0591E 00	1.7464E-02

JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
33	121.500	220.907	31.017	79.676	0.	2.8009E 00	2.5394E 00	-4.3413E-04
			-0.	-178.403	-0.	3.0317E-01	-1.6669E 00	1.9784E-02
34	142.500	212.732	31.017	79.676	0.	2.7860E 00	2.4984E 00	-3.4268E-03
			-0.	-178.403	-0.	4.7076E-01	-1.2308E 00	2.1528E-02
35	163.500	204.557	31.017	79.676	0.	2.7473E 00	2.3966E 00	-6.1697E-03
			-0.	-178.403	-0.	6.4804E-01	-7.6969E-01	2.2064E-02
36	174.000	200.470	0.	0.	0.	2.7201E 00	2.3253E 00	-7.3460E-03
			-0.	-0.	-0.	7.3663E-01	-5.3916E-01	2.1683E-02
37	183.375	194.049	48.315	70.540	0.	2.6697E 00	2.2509E 00	-8.4470E-03
			-0.	-179.918	-0.	8.7285E-01	-3.3832E-01	2.1032E-02
38	202.125	181.206	48.315	70.540	0.	2.5472E 00	2.0704E 00	-1.0717E-02
			-0.	-179.918	-0.	1.1317E 00	4.3618E-02	1.9483E-02
39	220.875	168.364	48.315	70.[illegible]0	0.	2.397[illegible]E 00	1.8496E 00	-1.2697E-02
			-0.	-179.918	-0.	1.3659E 00	3.8986E-01	1.7123E-02
40	239.625	155.521	48.315	70.540	0.	2.2252E 00	1.5969E 00	-1.4079E-02
			-0.	-179.918	-0.	1.5616E 00	6.7983E-01	1.3380E-02
41	249.000	149.100	0.	0.	0.	2.1339E 00	1.4627E 00	-1.4443E-02
			-0.	-0.	-0.	1.6385E 00	7.9438E-01	1.0811E-02
42	256.500	140.587	30.013	26.443	0.	2.0103E 00	1.3532E 00	-1.4667E-02
			-0.	-179.632	-0.	1.7178E 00	8.6596E-01	8.0436E-03
43	271.500	123.562	30.013	[illegible].443	0.	1.7579E 00	1.1295E 00	-1.5031E-02
			-0.	-179.632	-0.	1.8076E 00	9.4874E-01	2.7512E-03
44	286.500	106.537	30.013	26.443	0.	1.5012E 00	9.0199E-01	-1.5151E-02
			-0.	-179.632	-0.	1.8075E 00	9.5236E-01	-2.6003E-03
45	301.500	89.513	30.013	26.443	0.	1.2456E 00	6.7548E-01	-1.4873E-02
			-0.	-179.632	-0.	1.7124E 00	8.7248E-01	-8.4682E-03
46	309.000	81.000	0.	0.	0.	1.1206E 00	5.6472E-01	-1.4537E-02
			-0.	-0.	-0.	1.6255E 00	7.9804E-01	-1.1739E-02
47	314.062	70.875	35.777	17.889	0.	9.7555E-01	4.9163E-01	-1.4188E-02
			-0.	-179.235	-0.	1.4897E 00	7.3182E-01	-1.4862E-02
48	324.187	50.625	35.777	17.889	0.	6.9324E-01	3.4938E-01	-1.3798E-02
			-0.	-179.235	-0.	1.1368E 00	5.5888E-01	-1.9521E-02

JOINT	-X	-Y	FORCE-X	FORCE-Y	MCMENT	DISPL-X	DISPL-Y	ROTATION
49	334.312	30.375	35.777	17.889	C.	4.1569E-01	2.0950E-01	-1.3692E-02
			-0.	-179.235	-C.	7.0879E-01	3.4857E-01	-2.2319E-02
50	344.437	10.125	35.777	17.889	0.	1.9873E-01	6.9921E-02	-1.3715E-02
			-0.	-179.235	-0.	2.4031E-01	1.1817E-01	-2.3565E-02
51	349.500	0.	0.	0.	0.	0.	0.	-1.3720E-02
			0.	0.	-C.	0.	0.	-2.3701E-02

B. COMPUTER ANALYSIS

(i) 90 mph wind loading on structure
(ii) snow load on left half of structure

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
1	11.32	13.370	2.632	1	2	-2.31748E 03	1.03330E 03	7.81250E-01	2.31748E 03	-1.03330E 03	1.16965E 04 (i
						-8.80661E 02	9.83964E 02	-8.80340E 02	1.52528E 03	-9.83964E 02	-3.28628E 03
						2.99244E 03	3.12516E 02	-4.37500E-01	-2.99244E 03	-3.12516E 02	3.53816E 03 (ii
						1.13703E 03	2.97593E 02	1.13685E 03	1.86469E 03	-2.97593E 02	4.09201E 02
2	22.64	13.370	2.632	2	3	-2.31736E 03	9.53765E 02	-1.16958E 04	2.31736E 03	-9.53765E 02	3.32892E 04
						1.52519E 03	9.08222E 02	-3.28610E 03	5.96662E 03	-9.08222E 02	-7.72753E 03
						2.83197E 03	2.32312E 02	-3.53845E 03	-2.83197E 03	-2.32312E 02	8.79813E 03
						1.80378E 03	2.21220E 02	3.48173E 02	2.88561E 03	-2.21220E 02	-7.33661E 02
3	22.64	13.370	2.632	3	4	-2.31702E 03	8.74287E 02	-3.32895E 04	2.31702E 03	-8.74287E 02	5.30836E 04
						5.96681E 03	8.32540E 02	-7.72746E 03	1.03381E 04	-8.32540E 02	-1.17988E 04
						2.67230E 03	1.52204E 02	-8.79809E 03	-2.67230E 03	-1.52204E 02	1.22439E 04
						2.82494E 03	1.44936E 02	-7.94320E 02	3.53370E 03	-1.44936E 02	-1.[illegible]308E 03
4	22.64	13.370	2.632	4	5	-2.31716E 03	7.95002E 02	-5.30820E 04	2.31716E 03	-7.95002E 02	7.10810E 04
						1.00378E 04	7.57040E 02	-1.17985E 04	1.37399E 04	-7.57040E 02	-1.55006E 04
						2.51134E 03	7.19951E 01	-1.22448E 04	-2.51134E 03	-7.19951E 01	1.38747E 04
						3.47273E 03	6.85573E 01	-1.56441E 03	3.80797E 03	-6.85573E 01	-1.89966E 03
5	11.32	13.370	2.632	5	6	-2.31787E 03	7.16316E 02	-7.10751E 04	2.31787E 03	-7.16316E 02	7.91841E 04
						1.37384E 04	6.82112E 02	-1.54997E 04	1.54063E 04	-6.82112E 02	-1.71676E 04
						2.35169E 03	-8.20313E 00	-1.38769E 04	-2.35169E 03	8.20313E 00	1.37840E 04
						3.74777E 03	-7.81142E 00	-1.96077E 03	3.72865E 03	7.81142E 00	-1.94166E 03
6	11.34	13.370	2.632	6	7	-2.42162E 03	9.83828E 01	-7.91847E 04	2.42162E 03	-9.83828E 01	8.03009E 04
						1.53670E 04	9.36850E 01	-1.72071E 04	1.55966E 04	-9.36850E 01	-1.74367E 04
						2.27706E 03	5.92895E 02	-1.37908E 04	-2.27706E 03	-5.92895E 02	2.05173E 04
						3.70170E 03	5.64584E 02	-1.97141E 03	5.08523E 03	-5.64584E 02	-3.35494E 03
7	22.69	13.370	2.632	7	8	-2.42366E 03	1.99097E 01	-8.03062E 04	2.42366E 03	-1.99097E 01	8.07579E 04
						1.55969E 04	1.89590E 01	-1.74386E 04	1.56898E 04	-1.89590E 01	-1.75315E 04
						2.13941E 03	4.75568E 02	-2.05186E 04	-2.13941E 03	-4.75568E 02	3.13091E 04
						5.03370E 03	4.52860E 02	-3.40751E 03	7.25265E 03	-4.52860E 02	-5.62696E 03
8	22.69	13.370	2.632	8	9	-2.42178E 03	-5.95449E 01	-8.07580E 04	2.42178E 03	5.95449E 01	7.94064E 04
						1.56905E 04	-5.67016E 01	-1.75308E 04	1.54125E 04	5.67016E 01	-1.72528E 04
						2.00531E 03	3.56237E 02	-3.13073E 04	-2.00531E 03	-3.56237E 02	3.93902E 04
						7.20131E 03	3.39227E 02	-5.67752E 03	8.86385E 03	-3.39227E 02	-7.34006E 03
9	22.69	13.370	2.632	9	10	-2.42219E 03	-1.38976E 02	-7.94058E 04	2.42219E 03	1.38976E 02	7.62521E 04
						1.54122E 04	-1.32340E 02	-1.72528E 04	1.47636E 04	1.32340E 02	-1.66041E 04
						1.86956E 03	2.37862E 02	-3.93909E 04	-1.86956E 03	-2.37862E 02	4.47883E 04
						8.81241E 03	2.26504E 02	-7.39177E 03	9.92257E 03	-2.26504E 02	-8.50193E 03
10	11.35	13.370	2.632	10	11	-2.42469E 03	-2.17794E 02	-7.62494E 04	2.42469E 03	2.17794E 02	7.37784E 04
						1.47621E 04	-2.07394E 02	-1.66045E 04	1.42538E 04	2.07394E 02	-1.60963E 04
						1.73950E 03	1.18770E 02	-4.47897E 04	-1.73950E 03	-1.18770E 02	4.61376E 04
						9.87344E 03	1.13098E 02	-8.55163E 03	1.01507E 04	-1.13098E 02	-8.82888E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
11	11.36	13.370	2.632	11	12	-2.29563E 03	-8.05392E 02	-7.37735E 04	2.29563E 03	8.05392E 02	6.46207E 04
						1.43019E 04	-7.66934E 02	-1.60463E 04	1.24193E 04	7.66934E 02	-1.41637E 04
						1.65200E 03	5.42475E 02	-4.61409E 04	-1.65200E 03	-5.42475E 02	5.23048E 04
						1.01181E C4	5.16571E 02	-8.86280E 03	1.13859E 04	-5.16571E 02	-1.01306E 04
12	22.73	13.370	2.632	12	13	-2.29675E 03	-6.41901E 02	-6.46195E 04	2.29675E 03	6.41901E 02	5.00312E 04
						1.24166E 04	-6.11250E 02	-1.41638E 04	9.41801E 03	6.11250E 02	-1.11633E 04
						1.55206E 03	3.94196E 02	-5.23046E 04	-1.55206E 03	-3.94196E 02	6.12637E 04
						1.13479E 04	3.75373E 02	-1.01685E 04	1.31907E 04	-3.75373E 02	-1.20113E 04
13	22.73	13.370	2.632	13	14	-2.29606E 03	-4.77779E 02	-5.00319E 04	2.29606E 03	4.77779E 02	3.91735E 04
						9.41842E 03	-4.54965E 02	-1.11631E 04	7.18502E 03	4.54965E 02	-8.92975E 03
						1.45025E 03	2.45806E 02	-6.12630E 04	-1.45025E 03	-2.45806E 02	6.68492E 04
						1.31518E 04	2.34069E 02	-1.20498E 04	1.43008E 04	-2.34069E 02	-1.31988E 04
14	22.73	13.370	2.632	14	15	-2.29534E 03	-3.13712E 02	-3.91727E 04	2.29534E 03	3.13712E 02	3.20429E 04
						7.18513E 03	-2.98733E 02	-8.92931E 03	5.71863E 03	2.98733E 02	-7.46281E 03
						1.34944E 03	9.73390E 01	-6.68494E 04	-1.34944E 03	-9.73390E 01	6.90616E 04
						1.42626E 04	9.26910E 01	-1.32372E 04	1.47176E 04	-9.26910E 01	-1.34922E 04
15	11.36	13.370	2.632	15	16	-2.29591E 03	-1.49713E 02	-3.20422E 04	2.29591E 03	1.49713E 02	3.03414E 04
						5.71827E 03	-1.42564E 02	-7.46288E 03	5.36844E 03	1.42564E 02	-7.11305E 03
						1.24487E 03	-5.05547E 01	-6.90598E 04	-1.24487E 03	5.05547E 01	6.84863E 04
						1.46775E 04	-4.81407E 01	-1.37316E 04	1.45595E 04	4.81407E 01	-1.36136E 04
16	11.27	13.370	2.632	16	17	-2.20125E 03	-6.67607E 02	-3.03406E 04	2.20125E 03	6.67607E 02	2.28194E 04
						5.40425E 03	-6.35729E 02	-7.07693E 03	3.85727E 03	6.35729E 02	-5.52995E 03
						1.22575E 03	2.34191E 02	-6.84826E 04	-1.22575E 03	-2.34191E 02	7.11242E 04
						1.45515E 04	2.23008E 02	-1.36201E 04	1.50949E 04	-2.23008E 02	-1.41624E 04
17	22.54	13.370	2.632	17	18	-2.20050E 03	-5.03427E 02	-2.28191E 04	2.20050E 03	5.03427E 02	1.14743E 04
						3.85747E 03	-4.79388E 02	-5.52958E 03	1.52402E 03	4.79388E 02	-3.19614E 03
						1.16091E 03	6.80867E 01	-7.11230E 04	-1.16091E 03	-6.80867E 01	7.26572E 04
						1.507[illegible]0E 04	6.48355E 01	-1.41878E 04	1.53855E 04	-6.48355E 01	-1.43634E 04
18	22.54	13.370	2.632	18	19	-2.20183E 03	-3.39376E 02	-1.14741E 04	2.20183E 03	3.39376E 02	3.82639E 03
						1.52348E 03	-3.23171E 02	-3.19660E 03	-4.95321E 01	3.23171E 02	-1.62359E 03
						1.09597E 03	-9.80073E 01	-7.26562E 04	-1.09597E 03	9.80073E 01	7.04476E 04
						1.53606E 04	-9.33274E 01	-1.45278E 04	1.49064E 04	9.33274E 01	-1.40736E 04
19	22.54	13.370	2.632	19	20	-2.20205E 03	-1.75317E 02	-3.82669E 03	2.20205E 03	1.75317E 02	-1.24039E 02
						-4.95564E 01	-1.66946E 02	-1.62374E 03	-8.62159E 02	1.66946E 02	-8.11133E 02
						1.03094E 03	-2.64114E 02	-7.04475E 04	-1.03094E 03	2.64114E 02	6.44962E 04
						1.48816E 04	-2.51502E 02	-1.40982E 04	1.36576E 04	2.51502E 02	-1.28742E 04
20	11.27	13.370	2.632	20	21	-2.20151E 03	-1.08926E 01	1.25648E 02	2.20151E 03	1.08926E 01	-2.48547E 02
						-8.622[illegible]5E 02	-1.03725E 01	-8.10597E 02	-8.87563E 02	1.03725E 01	-7.85318E 02
						9.65812E C2	-4.29703E 02	-6.44924E 04	-9.65812E 02	4.29703E 02	5.96528E 04
						1.36320E 04	-4.09185E 02	-1.28981E 04	1.26366E 04	4.09185E 02	-1.19027E 04

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MCMENT	AXIAL FORCE	SHEAR	MOMENT
21	11.33	13.370	2.632	21	22	-2.12835E 03	-5.66854E 02	2.49156E 02	2.12835E 03	5.66854E 02	-6.66953E 03
						-8.59891E 02	-5.39786E 02	-7.57396E 02	-2.18046E 03	5.39786E 02	5.63175E 02
						1.04275E 03	-1.71840E 02	-5.96484E 04	-1.04275E 03	1.71840E 02	5.77002E 04
						1.26649E 04	-1.63634E 02	-1.18726E 04	1.22642E 04	1.63634E 02	-1.14719E 04
22	22.65	13.370	2.632	22	23	-2.12842E 03	-4.02572E 02	6.66773E 03	2.12842E 03	4.02572E 02	-1.57870E 04
						-2.18012E 03	-3.83349E 02	5.62777E 02	-4.05582E 03	3.83349E 02	2.43848E 03
						1.02241E 03	-3.50347E 02	-5.77000E 04	-1.02241E 03	3.50347E 02	4.97639E 04
						1.22564E 04	-3.33618E 02	-1.14795E 04	1.06241E 04	3.33618E 02	-9.84720E 03
23	22.65	13.370	2.632	23	24	-2.12837E 03	-2.38604E 02	1.57858E 04	2.12837E 03	2.38604E 02	-2.11908E 04
						-4.05554E 03	-2.27211E 02	2.43824E 03	-5.16727E 03	2.27211E 02	3.54996E 03
						1.00155E 03	-5.28419E 02	-4.97639E 04	-1.00155E 03	5.28419E 02	3.77937E 04
						1.06162E 04	-5.03187E 02	-9.85513E 03	8.15410E 03	5.03187E 02	-7.39304E 03
24	22.65	13.370	2.632	24	25	-2.12822E 03	-7.45020E 01	2.11904E 04	2.12822E 03	7.45020E 01	-2.28780E 04
						-5.16713E 03	-7.09445E 01	3.54994E 03	-5.51424E 03	7.09445E 01	3.89705E 03
						9.80449E 02	-7.06518E 02	-3.77936E 04	-9.80449E 02	7.06518E 02	2.17892E 04
						8.14607E 03	-6.72781E 02	-7.40105E 03	4.85422E 03	6.72781E 02	-4.10919E 03
25	11.33	13.370	2.632	25	26	-2.12741E 03	8.94570E 01	2.28779E 04	2.12741E 03	-8.94570E 01	-2.18651E 04
						-5.51392E 03	8.51854E 01	3.89735E 03	-5.30560E 03	-8.51854E 01	3.68903E 03
						9.58949E 02	-8.84555E 02	-2.17887E 04	-9.58949E 02	8.84555E 02	1.17699E 04
						4.84593E 03	-8.42317E 02	-4.11725E 03	2.78522E 03	8.42317E 02	-2.05654E 03
26	11.33	13.370	2.632	26	27	-2.09231E 03	-4.02891E 02	2.18655E 04	2.09231E 03	4.02891E 02	-2.64292E 04
						-5.29235E 03	-3.83652E 02	3.70244E 03	-6.23103E 03	3.83652E 02	4.64112E 03
						1.13722E 03	-6.39758E 02	-1.17690E 04	-1.13722E 03	6.39758E 02	4.52278E 03
						2.85276E 03	-6.09209E 02	-1.98861E 03	1.36234E 03	6.09209E 02	-4.98191E 02
27	22.65	13.370	2.632	27	28	-2.09171E 03	-2.38991E 02	2.64304E 04	2.09171E 03	2.38991E 02	-3.18443E 04
						-6.23104E 03	-2.27580E 02	4.64159E 03	-7.34459E 03	2.27580E 02	5.75515E 03
						1.13693E 03	-6.39853E 02	-4.52267E 03	-1.13693E 03	6.39853E 02	-9.97166E 03
						1.36221E 03	-6.09299E 02	-4.98278E 02	-1.61905E 03	6.09299E 02	2.48298E 03
28	22.65	13.370	2.632	28	29	-2.09140E 03	-7.49832E 01	3.18442E 04	2.09140E 03	7.49832E 01	-3.35428E 04
						-7.34445E 03	-7.14027E 01	5.75524E 03	-7.69383E 03	7.14027E 01	6.10463E 03
						1.13707E 03	-6.39845E 02	9.97154E 03	-1.13707E 03	6.39845E 02	-2.44657E 04
						-1.61897E 03	-6.09292E 02	2.48301E 03	-4.60020E 03	6.09292E 02	5.46423E 03
29	22.65	13.370	2.632	29	30	-2.09231E 03	8.89863E 01	3.35427E 04	2.09231E 03	-8.89863E 01	-3.15270E 04
						-7.69417E 03	8.47372E 01	6.10427E 03	-7.27956F 03	-8.47372E 01	5.68966F 03
						1.13687E 03	-6.39838E 02	2.44657E 04	-1.13687E 03	6.39838E 02	-3.89598E 04
						-4.60028E 03	-6.09285E 02	5.46416E 03	-7.58147E 03	6.09285E 02	8.44536E 03
30	11.33	13.370	2.632	30	31	-2.09078E 03	2.52764E 02	3.15265E 04	2.09078E 03	-2.52764E 02	-2.86630E 04
						-7.27888E 03	2.40695E 02	5.69014E 03	-6.68990E 03	-2.40695E 02	5.10116E 03
						1.13592E 03	-6.40176E 02	3.89591E 04	-1.13592E 03	6.40176E 02	-4.62106E 04
						-7.58169E 03	-6.09607E 02	8.44485E 03	-9.07322E 03	6.09607E 02	9.93638E 03

MEMBER	LENGTH	I	AREA	MA	MB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
31	11.27	13.370	2.632	31	32	-2.08838E 03	-2.84143E 02	2.86598E 04	2.08838E 03	2.84143E 02	-3.18613E 04
						-6.68834E 03	-2.70575E 02	5.10143E 03	-7.34683E 03	2.70575E 02	5.75992E 03
						1.26094E 03	-3.32828E 02	4.62094E 04	-1.26094E 03	3.32828E 02	-4.99592E 04
						-9.02547E 03	-3.16935E 02	9.98363E 03	-9.79674E 03	3.16935E 02	1.07549E 04
32	22.54	13.370	2.632	32	33	-2.08783E 03	-1.19423E 02	3.18584E 04	2.08783E 03	1.19423E 02	-3.45497E 04
						-7.34603E 03	-1.13721E 02	5.75953E 03	-7.39958E 03	1.13721E 02	6.31308E 03
						1.26119E 03	-3.32637E 02	4.99584E 04	-1.26119E 03	3.32637E 02	-5.74546E 04
						-9.79649E 03	-3.16753E 02	1.07548E 04	-1.13383E 04	3.16753E 02	1.22967E 04
33	22.54	13.370	2.632	33	34	-2.08739E 03	4.44875E 01	3.45500E 04	2.08739E 03	-4.44875E 01	-3.35476E 04
						-7.89948E 03	4.23633E 01	6.31331E 03	-7.69331E 03	-4.23633E 01	6.10714E 03
						1.26112E 03	-3.32813E 02	5.74540E 04	-1.26112E 03	3.32813E 02	-6.49542E 04
						-1.13382E 04	-3.16921E 02	1.22965E 04	-1.28809E 04	3.16921E 02	1.38392E 04
34	22.54	13.370	2.632	34	35	-2.08908E 03	2.08324E 02	3.35469E 04	2.08908E 03	-2.08324E 02	-2.88525E 04
						-7.69380E 03	1.98376E 02	6.10635E 03	-6.72823E 03	-1.98376E 02	5.14078E 03
						1.26053E 03	-3.32969E 02	6.49532E 04	-1.26053E 03	3.32969E 02	-7.24568E 04
						-1.28809E 04	-3.17070E 02	1.38388E 04	-1.44243E 04	3.17070E 02	1.53822E 04
35	11.27	13.370	2.632	35	36	-2.08628E 03	3.72929E 02	2.88534E 04	2.08628E 03	-3.72929E 02	-2.46539E 04
						-6.72735E 03	3.55121E 02	5.14203E 03	-5.86349E 03	-3.55121E 02	4.27817E 03
						1.26056E 03	-3.33120E 02	7.24558E 04	-1.26056E 03	3.33120E 02	-7.62004E 04
						-1.44241E 04	-3.17214E 02	1.53820E 04	-1.51959E 04	3.17214E 02	1.61[illegible]E 04
36	11.36	13.370	2.632	36	37	-2.11812E 03	-1.12335E 02	2.46542E 04	2.11812E 03	1.12335E 02	-2.59320E 04
						-5.87575E 03	-1.06971E 02	4.26623E 03	-6.13857E 03	1.06971E 02	4.52[illegible]E 03
						1.30387E 03	-3.83789E 01	7.62073E 04	-1.30387E 03	3.83789E 01	-7.66434E 04
						-1.51793E 04	-3.65463E 01	1.61700E 04	-1.52690E 04	3.65463E 01	1.62597E 04
37	22.73	13.370	2.632	37	38	-2.11762E 03	5.16494E 01	2.59513E 04	2.11762E 03	-5.16494E 01	-2.47574E 04
						-6.13822E 03	4.91831E 01	4.52909E 03	-5.89677E 03	-4.91831E 01	4.28763E 03
						1.30356E 03	-3.80487E 01	7.66419E 04	-1.30356E 03	3.80487E 01	-7.75067E 04
						-1.52688E 04	-3.62319E 01	1.62593E 04	-1.54466E 04	3.62319E 01	1.64372E 04
38	22.73	13.370	2.632	38	39	-2.11831E 03	2.15690E 02	2.47573E 04	2.11831E 03	-2.15690E 02	-1.98557E 04
						-5.89702E 03	2.05391E 02	4.28736E 03	-4.88884E 03	-2.05391E 02	3.27918E 03
						1.30337E 03	-3.82598E 01	7.75057E 04	-1.30337E 03	3.82598E 01	-7.83[illegible]E 04
						-1.54465E 04	-3.64329E 01	1.64369E 04	-1.56254E 04	3.64329E 01	1.66158E 04
39	22.73	13.370	2.632	39	40	-2.11759E 03	3.79541E 02	1.98555E 04	2.11759E 03	-3.79541E 02	-1.12298E 04
						-4.88853E 03	3.61417E 02	3.27942E 03	-3.11435E 03	-3.61417E 02	1.50523E 03
						1.30344E 03	-3.83008E 01	7.83744E 04	-1.30344E 03	3.83008E 01	-7.92451E 04
						-1.56252E 04	-3.64719E 01	1.66156E 04	-1.58042E 04	3.64719E 01	1.67947E 04
40	11.36	13.370	2.632	40	41	-2.11937E 03	5.43322E 02	1.12283E 04	2.11937E 03	-5.43322E 02	-5.03416E 03
						-3.11472E 03	5.17378E 02	1.50425E 03	-1.84479E 03	-5.17378E 02	2.34327E 02
						1.30325E 03	-3.86953E 01	7.92420E 04	-1.30325E 03	3.86953E 01	-7.96840E 04
						-1.58037E 04	-3.68476E 01	1.67940E 04	-1.58946E 04	3.68476E 01	1.68[illegible]E 04

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MEMBER	LENGTH	I	AREA	NA	NB	AXIAL FORCE	SHEAR	MOMENT	AXIAL FORCE	SHEAR	MOMENT
41	11.35	13.370	2.632	41	42	-2.18712E 03	6.69141E 00	5.05360E 03	2.18712E 03	-6.69141E 00	-4.97755E 03
						-1.87042E 03	6.37189E 00	2.08472E 02	-1.85478E 03	-6.37189E 00	1.92829E 02
						1.27300E 03	2.81592E 02	7.96797E 04	-1.27300E 03	-2.81592E 02	-7.64853E 04
						-1.59052E 04	2.68146E 02	1.68725E 04	-1.52482E 04	-2.68146E 02	1.62155E 04
42	22.69	13.370	2.632	42	43	-2.18639E 03	8.31494E 01	4.97611E 03	2.18639E 03	-8.31494E 01	-3.09149E 03
						-1.85462E 03	7.91790E 01	1.93225E 02	-1.46657E 03	-7.91790E 01	-1.94824E 02
						1.27338E 03	2.81856E 02	7.64824E 04	-1.27338E 03	-2.81856E 02	-7.00876E 04
						-1.52474E 04	2.68398E 02	1.62150E 04	-1.39321E 04	-2.68398E 02	1.48997E 04
43	22.69	13.370	2.632	43	44	-2.18661E 03	1.59586E 02	3.09116E 03	2.18661E 03	-1.59586E 02	5.30047E 02
						-1.46658E 03	1.51966E 02	-1.94976E 02	-7.21756E 02	-1.51966E 02	-9.39801E 02
						1.27319E 03	2.81800E 02	7.00867E 04	-1.27319E 03	-2.81800E 02	-6.36925E 04
						-1.39320E 04	2.68344E 02	1.48995E 04	-1.26168E 04	-2.68344E 02	1.35843E 04
44	22.69	13.370	2.632	44	45	-2.18664E 03	2.36186E 02	-5.29992E 02	2.18664E 03	-2.36186E 02	5.88902E 03
						-7.21779E 02	2.24908E 02	-9.39802E 02	3.80488E 02	-2.24908E 02	-2.04207E 03
						1.27331E 03	2.81609E 02	6.36915E 04	-1.27331E 03	-2.81609E 02	-5.73016E 04
						-1.26166E 04	2.68162E 02	1.35841E 04	-1.13023E 04	-2.68162E 02	1.22698E 04
45	11.35	13.370	2.632	45	46	-2.18681E 03	3.12406E 02	-5.88887E 03	2.18681E 03	-3.12406E 02	9.43308E 03
						3.80392E 02	2.97489E 02	-2.04210E 03	1.10938E 03	-2.97489E 02	-2.77109E 03
						1.27325E 03	2.81348E 02	5.72996E 04	-1.27325E 03	-2.81348E 02	-5.41095E 04
						-1.13019E 04	2.67913E 02	1.22694E 04	-1.06457E 04	-2.67913E 02	1.16132E 04
46	11.32	13.370	2.632	46	47	-2.19398E 03	-2.57482E 02	-9.43416E 03	2.19398E 03	2.57482E 02	6.52036E 03
						1.10698E 03	-2.45188E 02	-2.77404E 03	5.07555E 02	2.45188E 02	-2.17472E 03
						1.15931E 03	5.97234E 02	5.41070E 04	-1.15931E 03	-5.97234E 02	-4.73451E 04
						-1.06885E 04	5.68716E 02	1.15694E 04	-9.29767E 03	-5.68716E 02	1.01786E 04
47	22.64	13.370	2.632	47	48	-2.19386E 03	-1.80671E 02	-6.52155E 03	2.19386E 03	1.80671E 02	2.43109E 03
						5.07847E 02	-1.72044E 02	-2.17491E 03	-3.33495E 02	1.72044E 02	-1.33357E 03
						1.15931E 03	5.97502E 02	4.73433E 04	-1.15931E 03	-5.97502E 02	-3.38160E 04
						-9.29731E 03	5.68971E 02	1.01783E 04	-6.51495E 03	-5.68971E 02	7.39589E 03
48	22.64	13.370	2.632	48	49	-2.19382E 03	-1.04183E 02	-2.43146E 03	2.19382E 03	1.04183E 02	7.27344E 01
						-3.33405E 02	-9.92083E 01	-1.33363E 03	-8.18558E 02	9.92083E 01	-8.48479E 02
						1.15936E 03	5.97455E 02	3.38155E 04	-1.15936E 03	-5.97455E 02	-2.02890E 04
						-6.51483E 03	5.68926E 02	7.39580E 03	-3.73265E 03	-5.68926E 02	4.61362E 03
49	22.64	13.370	2.632	49	50	-2.19383E 03	-2.76689E 01	-7.28750E 01	2.19383E 03	2.76689E 01	-5.53562E 02
						-8.18533E 02	-2.63477E 01	-8.48511E 02	-9.47381E 02	2.63477E 01	-7.19663E 02
						1.15946E 03	5.97441E 02	2.02886E 04	-1.15946E 03	-5.97441E 02	-6.76247E 03
						-3.73253E 03	5.68913E 02	4.61358E 03	-9.50408E 02	-5.68913E 02	1.83146E 03
50	11.32	13.370	2.632	50	51	-2.19384E 03	4.88809E 01	5.53500E 02	2.19384E 03	-4.88809E 01	-1.25000E-01
						-9.47372E 02	4.65468E 01	-7.19679E 02	-8.33551E 02	-4.65468E 01	-8.33500E 02
						1.15947E 03	5.97352E 02	6.76234E 03	-1.15947E 03	-5.97352E 02	-1.87500E-01
						-9.50381E 02	5.68828E 02	1.83144E 03	4.40489E 02	-5.68828E 02	4.40564E 02

JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
1	-349.500	0.	0.	0.	0.	0.	0.	-8.1897E-02
			0.	0.	-0.	0.	0.	-7.5359E-02
2	-344.437	10.125	71.107	-35.553	0.	8.2799E-01	-4.1292E-01	-8.1402E-02
			-0.	-179.235	-0.	7.6193E-01	-3.8244E-01	-7.5209E-02
3	-334.312	30.375	71.107	-35.553	0.	2.4449E 00	-1.2191E 00	-7.7594E-02
			-0.	-179.235	-0.	2.2748E 00	-1.1416E 00	-7.4165E-02
4	-324.187	50.625	71.107	-35.553	0.	3.9487E 00	-1.9688E 00	-7.0281E-02
			-0.	-179.235	-0.	3.7585E 00	-1.8860E 00	-7.2389E-02
5	-314.062	70.875	71.107	-35.553	0.	5.2714E 00	-2.6280E 00	-5.9768E-02
			-0.	-179.235	-0.	5.2014E 00	-2.6099E 00	-7.0172E-02
6	-309.000	81.000	0.	0.	0.	5.8454E 00	-2.9138E 00	-5.3407E-02
			-0.	-0.	-0.	5.9055E 00	-2.9630E 00	-6.9001E-02
7	-301.500	89.512	59.650	-52.555	0.	6.2720E 00	-3.2883E 00	-4.6641E-02
			-0.	-179.632	-0.	6.4864E 00	-3.4762E 00	-6.7545E-02
8	-286.500	106.537	59.650	-52.555	0.	6.9512E 00	-3.8839E 00	-3.2973E-02
			-0.	-179.632	-0.	7.6003E 00	-4.4600E 00	-6.3147E-02
9	-271.500	123.562	59.650	-52.555	0.	7.3979E 00	-4.2747E 00	-1.9383E-02
			-0.	-179.632	-0.	8.6251E 00	-5.3653E 00	-5.7148E-02
10	-256.500	140.587	59.650	-52.555	0.	7.6161E 00	-4.4641E 00	-6.1742E-03
			-0.	-179.632	-0.	9.5375E 00	-6.1713E 00	-5.0005E-02
11	-249.000	149.100	0.	0.	0.	7.6421E 00	-4.4857E 00	1.9133E-04
			-0.	-0.	-0.	9.9463E 00	-6.5325E 00	-4.6147E-02
12	-239.625	155.521	-92.675	135.305	0.	7.6224E 00	-4.4551E 00	6.0724E-03
			-0.	-179.918	-0.	1.0229E 01	-6.9463E 00	-4.1964E-02
13	-220.875	168.364	-92.675	135.305	0.	7.4808E 00	-4.2449E 00	1.5817E-02
			-0.	-179.918	-0.	1.0706E 01	-7.6458E 00	-3.2311E-02
14	-202.125	181.206	-92.675	135.305	0.	7.2287E 00	-3.8733E 00	2.3398E-02
			-0.	-179.918	-0.	1.1051E 01	-8.1517E 00	-2.1423E-02
15	-183.375	194.049	-92.675	135.305	0.	6.8896E 00	-3.3748E 00	2.9451E-02
			-0.	-179.918	-0.	1.1252E 01	-8.4464E 00	-9.8720E-03
16	-174.000	200.470	0.	0.	0.	6.6927E 00	-3.0856E 00	3.2102E-02
			-0.	-0.	-0.	1.1296E 01	-8.5118E 00	-4.0270E-03

JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
17	-163.500	204.557	-59.494	152.828	0.	6.5576E 00	-2.7359E 00	3.4342E-02
			-0.	-178.403	-0.	$\boxed{1.1300E\ 01}$	$\boxed{-8.5236E\ 00}$	1.8556E-03
18	-142.500	212.732	-59.494	152.828	0.	6.2655E 00	-1.9803E 00	3.7232E-02
			-0.	-178.403	-0.	1.1235E 01	-8.3582E 00	1.3973E-02
19	-121.500	220.907	-59.494	152.828	0.	5.9568E 00	-1.1820E 00	3.8521E-02
			-0.	-178.403	-0.	1.1070E 01	-7.9378E 00	2.6033E-02
20	-100.500	229.082	-59.494	152.828	0.	5.6419E 00	-3.6790E-01	3.8833E-02
			-0.	-178.403	-0.	1.0809E 01	-7.2703E 00	3.7405E-02
21	-90.000	233.170	0.	0.	0.	5.4840E 00	4.0120E-02	3.8818E-02
			-0.	-0.	-0.	1.0645E 01	-6.8499E 00	4.2636E-02
22	-78.750	234.482	-19.004	162.895	0.	5.4341E 00	4.7579E-01	3.8525E-02
			-0.	-179.333	-0.	1.0585E 01	-6.3421E 00	4.7607E-02
23	-56.250	237.107	-19.004	162.895	0.	5.3370E 00	1.3243E 00	3.6622E-02
			-0.	-179.333	-0.	1.0447E 01	-5.1661E 00	5.6711E-02
24	-33.750	239.732	-19.004	162.895	0.	5.2466E 00	2.1150E 00	3.3490E-02
			-0.	-179.333	-0.	1.0287E 01	-3.8030E 00	6.4128E-02
25	-11.250	242.357	-19.004	162.895	0.	5.1653E 00	2.8273E 00	2.9757E-02
			-0.	-179.333	-0.	1.0111E 01	-2.2984E 00	6.9175E-02
26	0.	243.670	0.	0.	0.	5.1284E 00	3.1514E 00	2.7862E-02
			-0.	-0.	-0.	1.0019E 01	-1.5114E 00	7.0597E-02
27	11.250	242.357	19.004	162.895	0.	5.1646E 00	3.4536E 00	2.5816E-02
			-0.	-0.	-0.	1.0111E 01	-7.1267E-01	7.1287E-02
28	33.750	239.732	19.004	162.895	0.	5.2279E 00	3.9804E 00	2.0879E-02
			-0.	-0.	-0.	1.0297E 01	8.9081E-01	7.0825E-02
29	56.250	237.107	19.004	162.895	0.	5.2773E 00	4.3882E 00	1.5340E-02
			-0.	-0.	-0.	1.0479E 01	2.4563E 00	6.7908E-02
30	78.750	234.482	19.004	162.895	0.	5.3120E 00	4.6705E 00	9.8277E-03
			-0.	-0.	-0.	1.0650E 01	3.9285E 00	6.2535E-02
31	90.000	233.170	0.	0.	0.	5.3241E 00	4.7664E 00	7.2782E-03
			-0.	-0.	-0.	1.0729E 01	4.6123E 00	5.8927E-02
32	100.500	229.082	59.494	152.828	0.	5.3496E 00	4.8293E 00	4.7280E-03
			-0.	-0.	-0.	1.0961E 01	5.2103E 00	5.4875E-02

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JOINT	-X	-Y	FORCE-X	FORCE-Y	MOMENT	DISPL-X	DISPL-Y	ROTATION
33	121.500	220.907	59.494	152.828	C.	5.3673E 00	4.8700E 00	-8.6854E-04
			-0.	-0.	-C.	1.1373E 01	6.2702E 00	4.5823E-02
34	142.500	212.732	59.494	152.828	C.	5.3383E 00	4.7906E 00	-6.6075E-03
			-0.	-C.	-C.	1.1705E 01	7.1268E 00	3.5507E-02
35	163.500	204.557	59.494	152.828	C.	5.2639E 00	4.5946E 00	-1.1066E-02
			-0.	-C.	-0.	1.1948E 01	7.7534E 00	2.3927E-02
36	174.000	200.470	0.	C.	C.	5.2115E 00	4.4575E 00	-1.4121E-02
			-0.	-C.	-C.	1.2032E 01	7.9722E 00	1.7662E-02
37	183.375	194.049	92.675	135.305	0.	5.1148E 00	4.3146E 00	-1.6270E-02
			-0.	-C.	-C.	1.2125E 01	8.1077E 00	1.1167E-02
38	202.125	181.206	92.675	135.305	C.	4.8795E 00	3.9678E 00	-2.0579E-02
			-0.	-C.	-0.	1.2183E 01	8.1952E 00	-1.9342E-03
39	220.875	168.364	92.675	135.305	0.	4.5915E 00	3.5441E 00	-2.4370E-02
			-0.	-0.	-0.	1.2072E 01	8.0356E 00	-1.5182E-02
40	239.625	155.521	92.675	135.305	0.	4.2614E 00	3.0590E 00	-2.7012E-02
			-0.	-0.	-0.	1.1791E 01	7.6262E 00	-2.8579E-02
41	249.000	149.100	0.	C.	C.	4.0863E 00	2.8016E 00	-2.7704E-02
			-0.	-0.	-C.	1.1585E 01	7.3269E 00	-3.5332E-02
42	256.500	140.587	57.399	50.572	0.	3.8492E 00	2.5915E 00	-2.8130E-02
			-0.	-0.	-0.	1.1255E 01	7.0373E 00	-4.1958E-02
43	271.500	123.562	57.399	5C.572	C.	3.3653E 00	2.1626E 00	-2.8814E-02
			-0.	-C.	-C.	1.0433E 01	6.3141E 00	-5.4396E-02
44	286.500	106.537	57.399	5C.572	0.	2.8732E 00	1.7266E 00	-2.9032E-02
			-0.	-0.	-0.	9.4080E 00	5.4125E 00	-6.5747E-02
45	301.500	89.513	57.399	50.572	0.	2.3836E 00	1.2927E 00	-2.8487E-02
			-0.	-C.	-0.	8.1991E 00	4.3488E 00	-7.6014E-02
46	309.000	81.000	0.	0.	0.	2.1442E 00	1.0806E 00	-2.7837E-02
			-0.	-C.	-0.	7.5313E 00	3.7612E 00	-8.0741E-02
47	314.062	70.875	68.424	34.212	0.	1.8664E 00	9.4062E-01	-2.7162E-02
			-0.	-0.	-C.	6.6914E 00	3.3418E 00	-8.5036E-02
48	324.187	50.625	68.424	34.212	C.	1.3261E 00	6.6834E-01	-2.6404E-02
			-0.	-C.	-C.	4.8955E 00	2.4450E 00	-9.1907E-02

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JOINT	-X	-Y	FORCE-X	FORCE-Y	MCMENT	DISPL-X	CISPL-Y	ROTATION
49	334.312	30.375	68.424	34.212	C.	7.9511E-01	4.0073E-01	-2.6192E-02
			-0.	-0.	-0.	2.9837E 00	1.4902E 00	-9.6488E-02
50	344.437	10.125	68.424	34.212	C.	2.6534E-01	1.3374E-01	-2.6232E-02
			-0.	-0.	-C.	1.0023E 00	5.0064E-01	-9.6779E-02
51	349.500	0.	0.	0.	C.	0.	0.	-2.6256E-02
			0.	0.	-0.	0.	0.	-9.9065E-02

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APPENDIX B

END ARCH RIB STRUCTURAL ANALYSIS

Detail structural analysis of end arch which carries the fabric end wall is shown in this section. The language for programming is the standard STRUDL language under ICES system.[1]

Joint coordinate designations are shown in Figure B-1. Loads due to tension in the fabric are transferred to the arch AFK. The arch AFK and ground beam AOK subjected to these loads are analyzed and bending moments, axial load and shear force for all sections are tabulated in the results enclosed. It can be seen that the horizontal reaction at A or K exceeds the limits of ground anchors which had been employed up to this time. Therefore, assuming no change in ground anchors, a cable is needed to be connected between A and K to withstand 90 mph winds. A cable with a minimum working capacity of 8274 pounds is required.

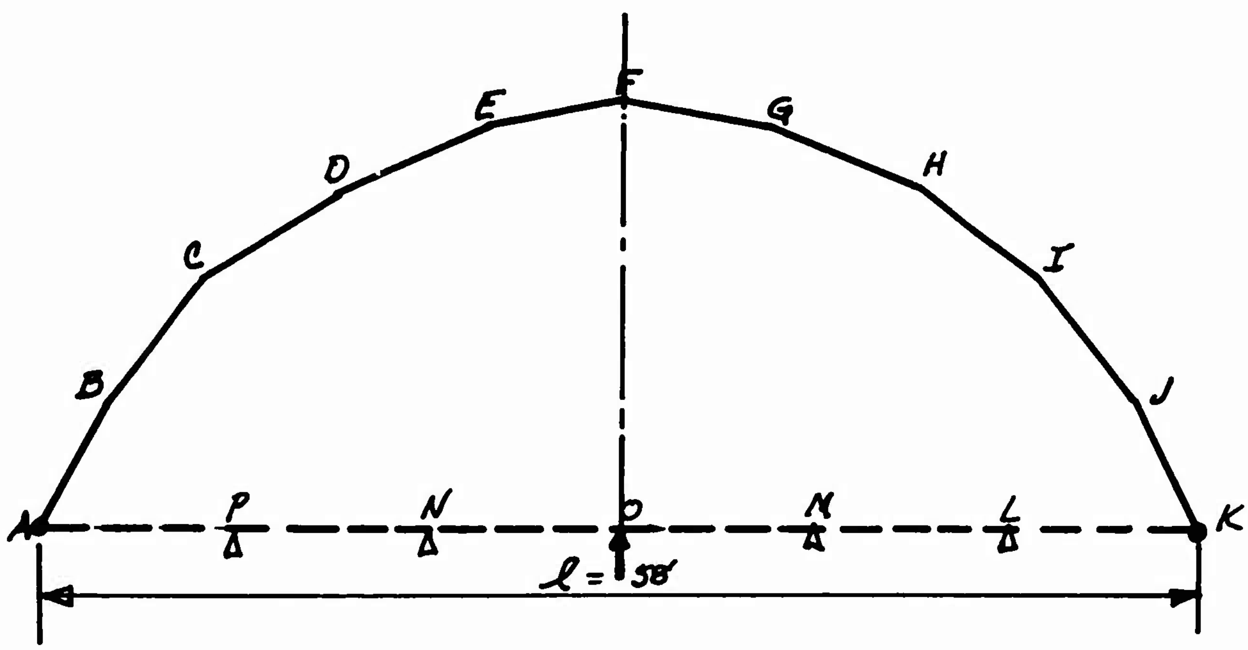

Figure B-1. Coordinate Designation

[1]ICES STRUDL-I, Vol. 1, Frame Analysis, School of Engineering, MIT.

A. **COMPUTER ANALYSIS**

90 mph wind loading on fabric end wall of hangar

```
STRUDL
        ***********************************************
        *                                             *
        *               ICES STRUDL-I                 *
        *       THE STRUCTURAL DESIGN LANGUAGE        *
        *                                             *
        *   CIVIL ENGINEERING SYSTEMS LABORATORY      *
        *  MASSACHUSETTS INSTITUTE OF TECHNOLOGY      *
        *      CAMBRIDGE, MASSACHUSETTS               *
        *          JUNE, 1968  MOD 2                  *
        *                                             *
        ***********************************************

TYPE PLANE FRAME
UNITS LB IN
JOINT COORDINATES
'A' -249.5 0. S
'B' -309. 81.
'C' -249. 1[illegible]
'D' -174. 200.[illegible]
'E' -90. 233.17
'F' 0 243.[illegible]
'G' 90. 233.17
```

```
'H' 174. 260.49
'I' 249. 149.1
'J' 309. 81.
'K' 349.5 0 S
'L' 210 0
'M' 105 0
'O' 0 0 S
'N' -105 0
'P' -210 0
JOINT 'A' 'K' 'O' RELEASE MOMENT Z
MEMBER INCIDENTS
'AB' 'A' 'B'
'BC' 'B' 'C'
'CD' 'C' 'D'
'DE' 'D' 'E'
'EF' 'E' 'F'
'FG' 'F' 'G'
'GH' 'G' 'H'
'HI' 'H'          'I'
'IJ' 'I' 'J'
'JK' 'J' 'K'
'KL' 'K' 'L'
'LM' 'L' 'M'
'MO' 'M' 'O'
'AP' 'A' 'P'
```

```
'NA' 'PI' 'NI'
'NO' 'NI' 'IJ'
LOADING 'TEMP'
MEMBERS 'AB' 'BC' 'CD' 'DE' 'EF' 'FG' 'GH' 'IJ' 'HI' 'JK' 'KL' 'LM' 'MC'
'AP' 'PN' 'NJ' TEMP LOADS AXIAL 150
LOADING 'WIND'
MEMBER LOADS
'AB' 'JK' F Y GLO CON FX -140.1 0.5
'BC' 'IJ' F Y GLO CON FX -575.5 0.5
'CD' 'HI' F Y GLO CON FX -1085.5 0.5
'DE' 'GH' F Y GLO CON FX -1526. 0.5
'EF' 'FG' F Y GLO CON FX -1818.75 0.5
'KL' FORCE Y CON P -140.2 L 21
'KL' FORCE Y CON P -400.6 L 42
'KL' FORCE Y CON P -575.5 L 75
'KL' FORCE Y CON P -922.5 L 102
'LM' FORCE Y CON P -1421 L 36
'LM' FORCE Y CON P -1526 L 75
'ML' FORCE Y CON P -1755 L 9
'MC' FORCE Y CON P -1818.8 L 57
'PN' FORCE Y CON P 1421 L 36
'PN' FORCE Y CON P 1526 L 75
'NG' FORCE Y CON P 1755 L 9
'NL' FORCE Y CON P 1818.8 L 57
'AP' FORCE Y CON P 140.2 L 21
'AF' FORCE Y CON P 400.6 L 42
```

```
'AP' FORCE Y CON P 575.5 L 75
'AP' FORCE Y CON P 922.5 L 102
JOINT LOADS
'B' 'J' FOR Y -400.6
'C' 'I' FOR Y -922.5
'D' 'H' FOR Y -1421
'E' 'G' FOR Y -1755
'F' FOR Y -1850.6
'P' 'L' FOR Y 1085.5
'U' FOR Y 1850.6
MEMBERS 'AB' 'BC' 'CD' 'DE' 'EF' 'FG' 'GH' 'IJ' 'HI' 'JK' 'KL' 'LM' 'MO' -
'AP' 'PN' 'NO' PROPERTIES PRISMATIC AX 9.12 IZ 106.5 IY 37.01
CONSTANTS E [illegible] ALL
CONSTANTS CTE 0.0000325 ALL
LOADING COMB 'TOTAL' COMB 'TEMP' 1 'WIND' 1
LOADING LIST ALL
MEMBER 'AP' 'KL' RELEASE START MOM Z
MEMBER 'MO' RELEASE END MOM Z
STIFFNESS
TIME FOR MODULE STCOMP FOR    16 MEMBERS=    2.98 SECONDS
TIME FOR MODULE SISTOP FOR    16 MEMBERS=    1.83 SECONDS
TIME FOR MODULE STKLOP=    0.28 SECONDS
TIME FOR MODULE STMLOP FOR    42 LOADS=    41.38 SECONDS
TIME FOR MODULE STASOP FOR    16 MEMBERS=    2.96 SECONDS
TIME FOR MODULE STJPJP FOR    16 JOINTS=    1.65 SECONDS
TIME FOR MODULE STSLOP FOR NSJL=    16 IS    3.42 SECONDS
TIME FOR MODULE STDIAS FOR    16 JOINTS EQUALS    0.01 SECONDS
TIME FOR MODULE STU3BS FOR    16 JOINTS EQUALS    4.C8 SECONDS
TIME FOR MODULE STBKSU FOR    16 MEMBERS=    20.88 SECONDS
PRINT DATA
```

```
****************************************
* PROBLEM DATA FROM INTERNAL STORAGE   *
****************************************

JOB ID   NONE        NAME -

ACTIVE   UNITS  LENGTH       WEIGHT        ANGLE      TEMPERATURE      TIME
                INCH         LB            RAD        DEGF             SEC

          ********** STRUCTURAL DATA **********

ACTIVE STRUCTURE TYPE - PLANE FRAME

ACTIVE COORDINATE AXES   X Y
```

JOINT COORDINATES					RELEASES					STATUS
JOINT	X	Y	Z	CONDITION	FORCE	MOMENT	THETA 1	THETA 2	THETA 3	
A	-349.500	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
B	-309.000	81.000	0.0							ACTIVE
C	-249.000	149.100	0.0							ACTIVE
D	-174.000	200.490	0.0							ACTIVE
E	-90.000	233.170	0.0							ACTIVE
F	0.0	243.670	0.0							ACTIVE
G	90.000	233.170	0.0							ACTIVE
H	174.000	200.490	0.0							ACTIVE
I	249.000	149.100	0.0							ACTIVE
J	309.000	81.000	0.0							ACTIVE
K	349.500	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
L	210.000	0.0	0.0							ACTIVE
M	105.000	0.0	0.0							ACTIVE
O	0.0	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
N	-105.000	0.0	0.0							ACTIVE
P	-210.000	0.0	0.0							ACTIVE

MEMBER INCIDENCES			LENGTH	RELEASES				STATUS
				START		END		
MEMBER	START	END	LOCAL COORD.	FORCE	MOMENT	FORCE	MOMENT	
AB	A	B	90.561					ACTIVE
BC	B	C	90.761					ACTIVE
CD	C	D	90.917					ACTIVE
DE	D	E	90.133					ACTIVE
EF	E	F	90.610					ACTIVE
FG	F	G	90.610					ACTIVE
GH	G	H	90.133					ACTIVE
HI	H	I	90.917					ACTIVE
IJ	I	J	90.761					ACTIVE
JK	J	K	90.561					ACTIVE
KL	K	L	139.500		Z			ACTIVE
LM	L	M	105.000					ACTIVE
MO	M	O	105.000				Z	ACTIVE
AP	A	P	139.500		Z			ACTIVE

PN	P	N	105.000	ACTIVE
NO	N	O	105.000	ACTIVE

MEMBER PROPERTIES

MEMBER	TYPE/SEG	SEG.L	COMP	AX	AY	AZ	IX	IY	IZ	SY	SZ
AB	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
BC	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
CD	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
DE	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
EF	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
FG	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
GH	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
HI	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
IJ	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
JK	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
KL	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
LM	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
MO	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
AP	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
PN	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
NO	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0

MEMBER DEPTH

MEMBER	Y DEPTH	Z DEPTH	Y CENTROID	Z CENTROID

MEMBER CONSTANTS

CONSTANT	STANDARD VALUE	DOMAIN.	VALUE	MEMBER LIST
E	9800000.000000	ALL		
G	0.0	ALL		
DENSITY	1.000000	ALL		
CTE	0.000012	ALL		
BETA	0.0	ALL		

?

*

?

* ********** LOADING DATA **********

? LOADING LIST TEMP WIND TOTAL

? LOADING - TEMP

MEMBER LOADS --/

MEMBER													
AB	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
BC	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
CD	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
DE	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
EF	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
FG	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
GH	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
HI	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
IJ	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
JK	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
KL	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
LM	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
MO	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
AP	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
PN	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
NO	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0

JOINT LOADS ---------------------------------/ ---------------------------------------/

JOINT FORCE X Y Z MOMENT X Y Z

JOINT DISPLACEMENTS---------------------------/ ---------------------------------------/

JOINT DISP. X Y Z ROT. X Y Z

JOINT FORCE ASSUMPTIONS --/

JOINT THETA 1 2 3 FORCE X Y Z MOMENT X Y Z

NO ASSUMPTIONS GIVEN FOR THIS LOADING

MEMBER FORCE ASSUMPTIONS -----------------------/ --/

MEMBER COMPONENT DISTANCE VALUE COMPONENT DISTANCE VALUE

NO ASSUMPTIONS GIVEN FOR THIS LOADING

LOADING - WIND

MEMBER LOADS --/

MEMBER									
AB	CONCEN.	LOAD GL FORCE	Y	FR	P	-140.100	L	0.500
BC	CONCEN.	LOAD GL FORCE	Y	FR	P	-575.500	L	0.500
CD	CONCEN.	LOAD GL FORCE	Y	FR	P	-1085.500	L	0.500
DE	CONCEN.	LOAD GL FORCE	Y	FR	P	-1526.000	L	0.500
EF	CONCEN.	LOAD GL FORCE	Y	FR	P	-1818.750	L	0.500
FG	CONCEN.	LOAD GL FORCE	Y	FR	P	-1818.750	L	0.500
GH	CONCEN.	LOAD GL FORCE	Y	FR	P	-1526.000	L	0.500
HI	CONCEN.	LOAD GL FORCE	Y	FR	P	-1085.500	L	0.500
IJ	CONCEN.	LOAD GL FORCE	Y	FR	P	-575.500	L	0.500
JK	CONCEN.	LOAD GL FORCE	Y	FR	P	-140.100	L	0.500
KL	CONCEN.	LOAD	FORCE	Y		P	-140.200	L	21.000
	CONCEN.	LOAD	FORCE	Y		P	-400.600	L	42.000
	CONCEN.	LOAD	FORCE	Y		P	-575.500	L	75.000
	CONCEN.	LOAD	FORCE	Y		P	-922.500	L	102.000
LM	CONCEN.	LOAD	FORCE	Y		P	-1421.000	L	36.000
	CONCEN.	LOAD	FORCE	Y		P	-1526.000	L	75.000
MO	CONCEN.	LOAD	FORCE	Y		P	-1755.000	L	9.000
	CONCEN.	LOAD	FORCE	Y		P	-1818.800	L	57.000
AP	CONCEN.	LOAD	FORCE	Y		P	140.200	L	21.000
	CONCEN.	LOAD	FORCE	Y		P	400.600	L	42.000
	CONCEN.	LOAD	FORCE	Y		P	575.500	L	75.000

	CONCEN.	LOAD	FORCE Y	P 922.500	L102.000
PN	CONCEN.	LOAD	FORCE Y	P 1421.000	L 36.000
	CONCEN.	LOAD	FORCE Y	P 1526.000	L 75.000
NO	CONCEN.	LOAD	FORCE Y	P 1755.000	L 9.000
	CONCEN.	LOAD	FORCE Y	P 1818.800	L 57.000

JOINT LOADS------------------------------/ ----------------------------------/

JOINT	FORCE X	Y	Z	MOMENT X	Y	Z
B	0.0	-400.600	0.0	0.0	0.0	0.0
C	0.0	-922.500	0.0	0.0	0.0	0.0
D	0.0	-1421.000	0.0	0.0	0.0	0.0
E	0.0	-1755.000	0.0	0.0	0.0	0.0
*F	0.0	-1850.600	0.0	0.0	0.0	0.0
G	0.0	-1755.000	0.0	0.0	0.0	0.0
H	0.0	-1421.000	0.0	0.0	0.0	0.0
I	0.0	-922.500	0.0	0.0	0.0	0.0
J	0.0	-410.600	0.0	0.0	0.0	0.0
L	0.0	1085.500	0.0	0.0	0.0	0.0
*O	0.0	1850.600	0.0	0.0	0.0	0.0
P	0.0	1085.500	0.0	0.0	0.0	0.0

JOINT DISPLACEMENTS-----------------------/ ----------------------------------/

JOINT	DISP. X	Y	Z	ROT. X	Y	Z

JOINT FORCE ASSUMPTIONS --/

JOINT	THETA 1	2	3	FORCE X	Y	Z	MOMENT X	Y	Z

NO ASSUMPTIONS GIVEN FOR THIS LOADING

MEMBER FORCE ASSUMPTIONS ---------------------/ ---------------------------------/

MEMBER	COMPONENT	DISTANCE	VALUE	COMPONENT	DISTANCE	VALUE

NO ASSUMPTIONS GIVEN FOR THIS LOADING

LOADING - TOTAL

COMBINATION GIVEN - TEMP 1.000 WIND 1.000

****
* END OF DATA FROM INTERNAL STORAGE *
****

****
RESULTS OF LATEST ANALYSES
****

PROBLEM - NONE TITLE -

ACTIVE UNITS INCH LB RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

LOADING - TEMP

MEMBER FORCES

MEMBER	JOINT	FORCE AXIAL	FORCE SHEAR Y	FORCE SHEAR Z	MOMENT TORSIONAL	MOMENT BENDING Y	MOMENT BENDING Z
AB	A	22.8563995	-45.7128296				0.4050109
AB	B	-22.8563995	45.7128296				-4140.1914062
BC	B	33.7865295	-38.3477020				4140.6875000
BC	C	-33.7865295	38.3477020				-7621.1757812
CD	C	42.1607513	-28.8985498				7621.1210937
CD	D	-42.1607513	28.8985498				-10247.5859375
DE	D	47.6307631	-18.5306396				10247.1328125
DE	E	-47.6307631	18.5306396				-11917.3593750
EF	E	50.7641754	-5.9224873				11916.9101562
EF	F	-50.7641754	5.9224873				-12453.5468750
FG	F	50.7641754	5.9224873				12453.9960937
FG	G	-50.7641754	-5.9224873				-11917.3593750
GH	G	47.6307631	18.5306396				11917.8125000
GH	H	-47.6307631	-18.5306396				-10247.5859375
HI	H	42.1607513	28.8985498				10247.6406250
HI	I	-42.1607513	-28.8985498				-7621.1757812
IJ	I	33.7865295	38.3477020				7620.6757812
IJ	J	-33.7865295	-38.3477020				-4140.1914062
JK	J	22.8563995	45.7128296				4139.7851562
JK	K	-22.8563995	-45.7128296				-0.0000000
KL	K	167580.0000000	0.0030000				0.0000000
KL	L	-167580.0000000	-0.0030000				0.0
LM	L	167580.0000000	0.0				0.0
LM	M	-167580.0000000	0.0				0.0
MO	M	167580.0000000	0.0				0.0
MO	O	-167580.0000000	0.0				0.0
AP	A	167580.0000000	0.0				0.0
AP	P	-167580.0000000	0.0				0.0
PN	P	167580.0000000	0.0				0.0
PN	N	-167580.0000000	0.0				0.0
NO	N	167580.0000000	0.0				0.0
NO	O	-167580.0000000	0.0				0.0

RESULTANT JOINT LOADS - SUPPORTS

JOINT	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	167631.1250000	-0.0000000				0.4050109
K	-167631.1250000	-0.0000000				-0.0000000
O	0.0	0.0				0.0

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0034201
K	0.0	0.0				-0.0034200
O	0.0	0.0				0.0

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-0.1963361	0.2879858				0.0032437
C	-0.2893503	0.5966972				0.0027417
D	-0.2709915	0.8714162				0.0019778
E	-0.1632070	1.0603456				0.0010384
F	0.0000001	1.1270990				0.0000000
G	0.1632075	1.0603485				-0.0010384
H	0.2709917	0.8714181				-0.0019778
I	0.2893488	0.5966967				-0.0027418
J	0.1964449	0.2879847				-0.0032437
L	0.0000000	0.0				0.0
M	0.0000000	0.0				0.0
N	-0.0000000	0.0				0.0
P	-0.0000000	0.0				0.0

LOADING - WIND

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR Y	SHEAR Z	TORSIONAL	BENDING Y	BENDING Z

855

AB	A	13154.5703125	-2673.3454590	-0.0002482
AB	B	-13329.2617187	2736.0002441	-244937.1875000
BC	B	12955.1093750	422.1242676	244937.1250000
BC	C	-12563.3007812	-41.6754728	-223889.5625000
CD	C	11647.8242187	2361.1003418	223889.5625000
CD	D	-11134.2578125	-1465.6425781	-49931.2812500
DE	D	9875.5351562	2615.1232910	49931.2304687
DE	E	-9342.2460937	-1192.9602051	121686.0000000
EF	E	9536.2578125	1766.7648926	-121685.9375000
EF	F	-9325.4960937	34.7320557	199929.5000000
FG	F	9325.4960937	39.7324066	-199929.5000000
FG	G	-9536.2578125	1766.7666484	121685.9375000
GH	G	9342.2460937	-1192.9599609	-121685.8750000
GH	H	-9875.5351562	2615.1230469	-49931.3164062
HI	H	11134.2578125	-1465.6423340	49931.3476562
HI	I	-11647.8242187	2361.1000977	-223889.6250000
IJ	I	12563.3007812	-41.6756287	223889.6875000
IJ	J	-12955.1093750	422.1240234	-244937.1875000
JK	J	13329.2578125	2736.0002441	244937.1875000
JK	K	-13156.5703125	-2673.3457031	-0.0000000
KL	K	0.0	2966.0229492	0.0000000
KL	L	0.0	-927.2231445	286374.5000000
LM	L	0.0	2012.7231445	-286374.5000000
LM	M	0.0	934.2766113	353881.4375000
MO	M	0.0	-934.2766113	-353881.4375000
MO	O	0.0	4508.0742187	0.0
AP	A	0.0	-4275.4843750	0.0
AP	P	0.0	2231.6867676	-468347.1250000
PN	P	0.0	-1146.1867676	468347.1250000
PN	N	0.0	-1600.8129883	-444867.7500000
NO	N	0.0	1600.8129883	444867.7500000
NO	O	0.0	-5374.6093750	0.0000000

RESULTANT JOINT LOADS - SUPPORTS

JOINT	/------- FORCE	-------	-------//	------- MOMENT	-------	-------/
	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	8274.0156250	6299.7617187				-0.0002482
K	-8274.0156250	13536.2695312				-0.0000000
O	0.0	-866.5363770				0.0000000

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	/------- DISPLACEMENT	-------	-------//	------- ROTATION	-------	-------/
	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0210007
K	0.0	0.0				-0.0210007
O	0.0	0.0				-0.0556439

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-[illegible]6088	0.6990735				0.0106305
C	-1.4613671	0.7289653				-0.0090101
D	-[illegible].6857144	-0.4526426				-0.0198465
E	-0.0784410	-2.0403185				-0.0154470
F	[illegible]0003	-2.7864323				0.0000000
G	0.0784416	-2.0403185				0.0154470
H	[illegible]7150	-0.4526423				0.0198465
I	1.4813671	0.7289652				0.0090101
J	[illegible]276097	0.6990739				-0.0106305
L	0.0	-3.9431076				0.0137164
M	[illegible]	-3.6130877				-0.0211703
N	0.0	4.9203787				-0.0306258
P	[illegible]	5.6142845				0.0177382

LOADING - TOTAL

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR Y	SHEAR Z	TORSIONAL	BENDING Y	BENDING Z
AB	A	13177.4257812	-2719.0581055				0.4047627
AB	B	-1305[illegible]	2781.7128906				-249077.3750000
BC	B	1302[illegible].0945312	383.7763672				249077.8125000
BC	C	-1259[illegible]	-3.3281708				-231510.6875000
CD	C	1168[illegible].9843750	2332.2116699				231510.6250000
CD	D	-1107[illegible].4179687	-1436.7539062				-60178.8671875
DE	D	994[illegible].1640625	2596.5925293				60178.3632812
DE	E	-935[illegible]750000	-1174.4294434				109768.6250000
EF	E	5567.0195312	1760.8422852				-109769.0000000
EF	F	-837[illegible]125	45.6545410				187475.9375000
FG	F	837[illegible].2578125	45.6548920				-187475.5000000
FG	G	-658[illegible]312	1760.8420410				109768.5625000
GH	G	538[illegible].8750000	-1174.4291992				-109768.0625000
GH	H	-994[illegible].1640625	2596.5922852				-60178.9023437
HI	H	1107[illegible].4179687	-1436.7536621				60178.9882812
HI	I	-1168[illegible]3750	2332.2114258				-231510.7500000
IJ	I	12597.0859375	-3.3279266				231510.3125000
IJ	J	-1302[illegible]5312	383.7761230				-249077.3750000
JK	J	1305[illegible].1132812	2781.7128906				249076.9375000
JK	K	-1317[illegible].4257812	-2719.0583496				-0.0000000
KL	K	16758[illegible].0000000	2966.0229492				0.0000000
KL	L	-16758[illegible]	-927.2231445				286374.5000000
LM	L	16758[illegible].0000000	2012.7231445				-286374.5000000
LM	M	-16758[illegible]0000	934.2760113				353881.4375000
MO	M	16758[illegible].0000000	-934.2766113				-353881.4375000
MO	O	-16758[illegible]	4508.0742187				0.0
AP	A	16758[illegible].0000000	-4270.4843750				0.0
AP	P	-16758[illegible]000	2231.6807676				-468347.1250000
PN	P	16758[illegible].0000000	-1146.1867676				468347.1250000
PN	N	-16758[illegible]00000	-1800.8129883				-444867.7500000
NO	N	16758[illegible].0000000	1800.8129883				444867.7500000
NO	O	-16758[illegible]0000	-5374.6093750				0.0000000

RESULTANT JOINT LOADS - SUPPORTS

JOINT	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	175905.1250000	6299.7617187				0.4047627
K	-175905.1250000	13536.2695312				-0.0000000
O	0.0	-866.5363770				0.0000000

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0244207
K	0.0	0.0				-0.0244207
O	0.0	0.0				-0.0556439

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-1.6241446	0.9870593				0.0138742
C	-1.7707167	1.3256617				-0.0062684
D	-0.9567659	0.4187735				-0.0178687
E	-0.2416480	-0.9739728				-0.0144086
F	0.0000004	-1.6593332				0.0000000
G	0.2416491	-0.9799700				0.0144086
H	0.9567666	0.4187757				0.0178686
I	1.7707157	1.3256617				0.0062683
J	1.6241436	0.9870586				-0.0138742
L	0.0000030	-3.9431076				0.0137164
M	0.0000000	-3.6130877				-0.0211703
N	-0.0000000	4.9203787				-0.0306258
P	-0.0000000	5.0142845				0.0177382

```
CHANGE
JOINT COORDINATES
'P' -210 0 S
'O' 0 0 S
'L' 210 0 S
'M' 105 0 S
'N' -105 0 S
'E' -90. 233.17 S
'G' 90 233.17 S
JOINT 'P' 'O' 'L' 'M' 'N'  'E' 'G' RELEASE MOM Z
MEMBER 'AP' 'KL' RELEASE START MOM Z END MOM Z
STIFFNESS
TIME FOR MODULE STCOMP FOR   16 MEMBERS=     3.52 SECONDS
TIME FOR MODULE STSTOP FOR   16 MEMBERS=     1.90 SECONDS
TIME FOR MODULE STRLOP=    0.29 SECONDS
TIME FOR MODULE STMDOP FOR   42 LOADS=      39.83 SECONDS
TIME FOR MODULE STASOP FOR   16 MEMBERS=     2.90 SECONDS
TIME FOR MODULE STJPOP FOR   16 JOINTS=     2.49 SECONDS
TIME FOR MODULE STSLOP FOR NSOL=   16 IS     3.38 SECONDS
TIME FOR MODULE STU1BS FOR   16 JOINTS EQUALS     0.02 SECONDS
TIME FOR MODULE STD3HS FOR   16 JOINTS EQUALS    21.70 SECONDS
TIME FOR MODULE STBKSB FOR   16 MEMBERS=    45.40 SECONDS
PRINT DATA
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0JJC

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*****************************************
*  PROBLEM DATA FROM INTERNAL STORAGE   *
*****************************************

JOB ID   NONE        NAME -

ACTIVE  UNITS  LENGTH      WEIGHT       ANGLE       TEMPERATURE      TIME
               INCH          LB           RAD          DEGF           SEC

          ********** STRUCTURAL DATA **********

ACTIVE STRUCTURE TYPE - PLANE FRAME

ACTIVE COORDINATE AXES   X Y
```

JOINT COORDINATES / RELEASES / STATUS

JOINT	X	Y	Z	CONDITION	FORCE	MOMENT	THETA 1	THETA 2	THETA 3	STATUS
A	-349.500	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
B	-309.000	81.000	0.0							ACTIVE
C	-249.000	149.100	0.0							ACTIVE
D	-174.000	200.490	0.0							ACTIVE
E	-90.000	233.170	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
F	0.0	243.670	0.0							ACTIVE
G	90.000	233.170	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
H	174.000	200.490	0.0							ACTIVE
I	249.000	149.100	0.0							ACTIVE
J	309.000	81.000	0.0							ACTIVE
K	349.500	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
L	210.000	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
M	105.000	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
O	0.0	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
N	-105.000	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
P	-210.000	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE

MEMBER INCIDENCES / LENGTH / RELEASES / STATUS

MEMBER	START	END	LENGTH LOCAL COORD.	START FORCE	START MOMENT	END FORCE	END MOMENT	STATUS
AB	A	B	90.561					ACTIVE
BC	B	C	90.761					ACTIVE
CD	C	D	90.917					ACTIVE
DE	D	E	90.133					ACTIVE
EF	E	F	90.610					ACTIVE
FG	F	G	90.610					ACTIVE
GH	G	H	90.133					ACTIVE
HI	H	I	90.917					ACTIVE
IJ	I	J	90.761					ACTIVE
JK	J	K	90.561					ACTIVE
KL	K	L	139.500		Z		Z	ACTIVE
LM	L	M	105.000					ACTIVE
MO	M	O	105.000				Z	ACTIVE
AP	A	P	139.500		Z		Z	ACTIVE

PN	P	N	105.000	ACTIVE
NU	N	J	105.000	ACTIVE

MEMBER PROPERTIES

MEMBER	TYPE/SEG	SEG.L	COMP	AX	AY	AZ	IX	IY	IZ	SY	SZ
AB	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
BC	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
CD	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
DE	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
EF	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
FG	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
GH	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
HI	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
IJ	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
JK	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
KL	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
LM	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
MO	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
AP	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
PN	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0
NO	PRISMATIC			9.120	0.0	0.0	0.0	37.010	108.500	0.0	0.0

MEMBER DEPTH

MEMBER	Y DEPTH	Z DEPTH	Y CENTROID	Z CENTROID

MEMBER CONSTANTS

CONSTANT	STANDARD VALUE	DOMAIN.	VALUE	MEMBER LIST
E	960000.000000	ALL		
G	0.0	ALL		
DENSITY	1.000000	ALL		
CTE	0.000012	ALL		
BETA	0.0	ALL		

*********** LOADING DATA ***********

LOADING LIST TEMP WIND TOTAL

LOADING - TEMP

CEEC

MEMBER LOADS

MEMBER													
AB	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
BC	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
CD	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
DE	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
EF	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
FG	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
GH	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
HI	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
IJ	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
JK	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
KL	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
LM	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
MO	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
AP	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
PN	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0
NO	TEMPERATURE LOAD	LA	0.0	LB	1.000	AXIAL	150.000	BENDING	Y	0.0	Z	0.0

JOINT LOADS

JOINT FORCE X Y Z MOMENT X Y Z

JOINT DISPLACEMENTS

JOINT DISPL X Y Z ROT. X Y Z

JOINT FORCE ASSUMPTIONS

JOINT THETA 1 2 3 FORCE X Y Z MOMENT X Y Z

NO ASSUMPTIONS GIVEN FOR THIS LOADING

MEMBER FORCE ASSUMPTIONS

MEMBER COMPONENT DISTANCE VALUE COMPONENT DISTANCE VALUE

NO ASSUMPTIONS GIVEN FOR THIS LOADING

LOADING - WIND

MEMBER LOADS

MEMBER										
AB	CONCEN.	LOAD GL	FORCE	Y	FR	P	-140.100	L	0.500
BC	CONCEN.	LOAD GL	FORCE	Y	FR	P	-575.500	L	0.500
CD	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1085.500	L	0.500
DE	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1525.000	L	0.500
EF	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1618.750	L	0.500
FG	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1618.750	L	0.500
GH	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1526.000	L	0.500
HI	CONCEN.	LOAD GL	FORCE	Y	FR	P	-1085.500	L	0.500
IJ	CONCEN.	LOAD GL	FORCE	Y	FR	P	-575.500	L	0.500
JK	CONCEN.	LOAD GL	FORCE	Y	FR	P	-140.100	L	0.500
KL	CONCEN.	LOAD	FORCE	Y		P	-140.200	L	21.000
	CONCEN.	LOAD	FORCE	Y		P	-400.600	L	42.000
	CONCEN.	LOAD	FORCE	Y		P	-575.500	L	75.000
	CONCEN.	LOAD	FORCE	Y		P	-922.500	L	102.000
LM	CONCEN.	LOAD	FORCE	Y		P	-1421.000	L	36.000
	CONCEN.	LOAD	FORCE	Y		P	-1526.000	L	75.000
MO	CONCEN.	LOAD	FORCE	Y		P	-1755.000	L	9.000
	CONCEN.	LOAD	FORCE	Y		P	-1818.800	L	57.000
AP	CONCEN.	LOAD	FORCE	Y		P	140.200	L	21.000
	CONCEN.	LOAD	FORCE	Y		P	400.600	L	42.000
	CONCEN.	LOAD	FORCE	Y		P	575.500	L	75.000

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              CONCEN.   LOAD    FORCE   Y       P   922.500    L102.000
PN            CONCEN.   LOAD    FORCE   Y       P  1421.000    L 36.000
              CONCEN.   LOAD    FORCE   Y       P  1526.000    L 75.000
NO            CONCEN.   LOAD    FORCE   Y       P  1755.000    L  9.000
              CONCEN.   LOAD    FORCE   Y       P  1818.800    L 57.000

JOINT LOADS-----------------------------/ ------------------------------/

JOINT     FORCE X        Y            Z        MOMENT X        Y         Z
B             0.0     -460.600       0.0           0.0          0.0       0.0
C             0.0     -922.500       0.0           0.0          0.0       0.0
D             0.0    -1421.000       0.0           0.0          0.0       0.0
E             0.0    -1755.000       0.0           0.0          0.0       0.0
F             0.0    -1850.600       0.0           0.0          0.0       0.0
G             0.0    -1755.000       0.0           0.0          0.0       0.0
H             0.0    -1421.000       0.0           0.0          0.0       0.0
I             0.0     -922.500       0.0           0.0          0.0       0.0
J             0.0     -460.500       0.0           0.0          0.0       0.0
L             0.0     1065.500       0.0           0.0          0.0       0.0
O             0.0     1850.600       0.0           0.0          0.0       0.0
P             0.0     1085.500       0.0           0.0          0.0       0.0

JOINT DISPLACEMENTS---------------------/ ------------------------------/

JOINT     DISP. X        Y            Z        ROT.  X         Y         Z

JOINT FORCE ASSUMPTIONS ------------------------------------------------------------------/

JOINT     THETA 1        2        3     FORCE X        Y         Z       MOMENT X        Y         Z
NO ASSUMPTIONS GIVEN FOR THIS LOADING

MEMBER FORCE ASSUMPTIONS ---------------------/     ------------------------------/

MEMBER      COMPONENT    DISTANCE      VALUE          COMPONENT    DISTANCE     VALUE
NO ASSUMPTIONS GIVEN FOR THIS LOADING

LOADING - TOTAL

          COMBINATION GIVEN -    TEMP        1.000       WIND        1.000

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*  END OF DATA FROM  INTERNAL STORAGE  *
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****
RESULTS OF LATEST ANALYSES
****

PROBLEM - NONE   TITLE -

ACTIVE UNITS INCH LB RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE   FRAME

ACTIVE COORDINATE AXES X Y

LOADING - TEMP

MEMBER FORCES

MEMBER	JOINT	FORCE AXIAL	FORCE SHEAR Y	FORCE SHEAR Z	MOMENT TORSIONAL	MOMENT BENDING Y	MOMENT BENDING Z
AB	A	6864.5429687	-1671.6828613				0.4073464
AB	B	-6864.5429687	1671.6828613				-151389.2500000
BC	B	7063.3007812	139.2461853				151389.6875000
BC	C	-7063.3007812	-139.2461853				-138751.5625000
CD	C	6813.3515625	1867.5715332				138751.4375000
CD	D	-6813.3515625	-1867.5715332				31042.8203125
DE	D	6209.1953125	3369.7873535				-31043.3945312
DE	E	-6209.1953125	-3369.7873535				334772.8125000
EF	E	76569.3750000	-8933.0898437				-334773.0625000
EF	F	-76569.3750000	8933.0898437				-474658.2500000
FG	F	76569.3750000	8933.0976562				474658.5000000
FG	G	-76569.3750000	-8933.0976562				334773.4375000
GH	G	6209.2109375	-3369.7941895				-334772.8750000
GH	H	-6209.2109375	3369.7941895				31042.8593750
HI	H	6813.3671875	-1867.5754395				-31042.7734375
HI	I	-6813.3671875	1867.5754395				-138751.8750000
IJ	I	7063.3125000	-139.2463837				138751.3750000
IJ	J	-7063.3125000	139.2463837				-151389.5625000
JK	J	6864.0585937	1671.6865234				151389.1250000
JK	K	-6864.0585937	-1671.6865234				-0.0000000
KL	K	167580.0000000	0.0				0.0
KL	L	-167580.0000000	0.0				0.0
LM	L	167580.0000000	0.0				0.0
LM	M	-167580.0000000	0.0				0.0
MO	M	167580.0000000	0.0				0.0
MO	O	-167580.0000000	0.0				0.0
AP	A	167580.0000000	0.0				0.0000000
AP	P	-167580.0000000	0.0				-0.0000000
PN	P	167580.0000000	0.0				0.0
PN	N	-167580.0000000	0.0				0.0
NO	N	167580.0000000	0.0				0.0
NO	O	-167580.0000000	0.0				0.0

OCCO

RESULTANT JOINT LOADS - SUPPORTS

JOINT	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	172144.8750000	5391.7890625				0.4073464
E	72523.8125000	-5391.7851562				-0.2401161
G	-72523.9125000	-5391.8007812				0.5738825
K	-172144.9375000	5391.7968750				-0.0000000
L	-0.0052761	0.0				0.0
M	0.0	0.0				0.0
O	0.0	0.0				0.0
N	0.0	0.0				0.0
P	0.0052761	0.0				-0.0000000

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0138903
E	0.0	0.0				0.0059602
G	0.0	0.0				-0.0059602
K	0.0	0.0				-0.0138902
L	0.0	0.0				0.0
M	0.0	0.0				0.0
O	0.0	0.0				0.0
N	0.0	0.0				0.0
P	0.0	0.0				0.0

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-0.8782178	0.6211766				0.0074434
C	-0.8495920	0.8132023				-0.0049396
D	-0.2803449	0.2717536				-0.0095444
F	-0.0000000	0.7962293				-0.0000000
H	0.2803450	0.2717540				0.0095444
I	0.8495916	0.8132020				0.0049395
J	0.8782173	0.6211763				-0.0074434

LOADING - WIND

MEMBER FORCES

MEMBER	JOINT	FORCE AXIAL	FORCE SHEAR Y	FORCE SHEAR Z	MOMENT TORSIONAL	MOMENT BENDING Y	MOMENT BENDING Z
AB	A	[illegible]008.3476562	-472.7492676				-0.0085090
AB	B	-[illegible]883.0[illegible]90625	535.4040527				-45649.5585937
BC	B	[illegible]523.7578125	722.0427246				45649.5156250
BC	C	-[illegible]051.9[illegible]53125	-341.5942363				2618.9938965
CD	C	[illegible]331.1601562	819.1838379				-2618.9990234
CD	D	-[illegible]717.59[illegible]5059	76.2733800				36390.6210937
DE	D	[illegible]122.1013184	-552.1555176				-36390.5625000
DE	E	-[illegible]568.8122559	1974.3186035				-77468.8750000
EF	E	[illegible]974.2812500	2065.0621094				77468.9375000
EF	F	-[illegible]763.5234375	-259.1650391				27857.7968750
FG	F	[illegible]763.5234375	-259.1643066				-27857.8125000
FG	G	-[illegible]2500	2065.6613770				-77468.9375000
GH	G	[illegible]568.8115234	1974.3190918				77468.8750000
GH	H	-[illegible]122.1005859	-552.1560059				36390.6367187
HI	H	[illegible]717.5927734	76.2741241				-36390.6328125
HI	I	-[illegible]1562	819.1835938				2619.0136719
IJ	I	[illegible]091.9453125	-341.5942383				-2618.9702148
IJ	J	-[illegible]9062	722.0427246				-45649.5429687
JK	J	[illegible]883.0390625	535.4033086				45649.5507812
JK	K	-[illegible]6562	-472.7492676				0.0000000
KL	K	0.0	913.1589355				0.0000000
KL	L	0.0	1125.6406250				0.0000000
LM	L	0.0	898.6037598				-0.0000000
LM	M	0.0	2048.3959961				-49475.5976562
MO	M	0.0	2907.2189941				49475.5976562
MO	O	0.0	666.5805664				0.0
AP	A	0.0	-913.1589355				-0.0000000
AP	P	0.0	-1125.6406250				-0.0000000
PN	P	0.0	-898.6037598				0.0000000
PN	N	0.0	-2048.3959961				49475.5976562
NO	N	0.0	-2907.2189941				-49475.5976562
NO	O	0.0	-666.5805664				0.0000000

RESULTANT JOINT LOADS - SUPPORTS

JOINT	FORCE X FORCE	FORCE Y FORCE	FORCE Z FORCE	MOMENT X MOMENT	MOMENT Y MOMENT	MOMENT Z MOMENT
A	[illegible]109.8552246	4249.4492187				-0.0085090
E	[illegible]584.8093262	3652.6389160				0.0152220
G	-[illegible]584.8095145	3652.6386719				-0.0587841
K	-[illegible]109.8547363	6075.7695312				0.0000000
L	0.0	2024.2443848				-0.0000000
M	0.0	4955.6132812				-0.0000000
O	0.0	-0.0000000				0.0000000
N	0.0	-4955.6132812				0.0000000
P	0.0	-2024.2443848				0.0000000

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0015668
E	0.0	0.0				0.0003702
G	0.0	0.0				-0.0003702
K	0.0	0.0				-0.0015668
L	0.0	0.0				0.0007965
M	0.0	0.0				-0.0000370
O	0.0	0.0				-0.0006472
N	0.0	0.0				-0.0000370
P	0.0	0.0				0.0007965

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-0.0795648	0.0330468				-0.0003168
C	0.0118128	-0.0546459				-0.0017848
D	0.0472136	-0.1136990				0.0007531
F	-0.0000000	-0.0513456				-0.0000000
H	-0.0473135	-0.1136991				-0.0007531
I	-0.0118128	-0.0546459				0.0017848
J	0.0795649	0.0330469				0.0003168

LOADING - TOTAL

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR Y	SHEAR Z	TORSIONAL	BENDING Y	BENDING Z
AB	A	12872.3906250	-2144.4321289				0.3988374
AB	B	-12747.0820312	2207.0869141				-197038.7500000
BC	B	12587.0585937	861.2888184				197039.1875000
BC	C	-12155.2460937	-480.8403320				-136132.5625000
CD	C	11144.5117187	2686.7553711				136132.4375000
CD	D	-10530.9414062	-1791.2976074				67433.4375000
DE	D	9331.2929687	2817.6318359				-67433.9375000
DE	E	-8778.0039062	-1395.4687500				257303.9375000
EF	E	82543.6250000	-6867.4257812				-257304.1250000
EF	F	-82332.8750000	8673.9218750				-446800.4375000
FG	F	82332.8750000	8673.9296875				446800.6875000
FG	G	-82543.6250000	-6867.4335937				257304.5000000
GH	G	8778.0195312	-1395.4750977				-257304.0000000
GH	H	-9331.3085937	2817.6381836				67433.4375000
HI	H	10530.9570312	-1791.3012695				-67433.3750000
HI	I	-11144.5273437	2686.7593332				-136132.8125000
IJ	I	12155.2576125	-480.8405762				136132.3750000
IJ	J	-12587.0664062	861.2890625				-197039.0625000
JK	J	12747.0976562	2207.0903320				197038.6250000
JK	K	-12872.4062500	-2144.4357910				-0.0000000
KL	K	167580.0000000	913.1589355				0.0000000
KL	L	-167580.0000000	1125.6406250				0.0000000

LM	L	167580.0000000	898.6037598	-0.0000000
LM	M	-167580.0000000	2048.3959961	-49475.5976562
MO	M	167580.0000000	2907.2189941	49475.5976562
MO	O	-167580.0000000	666.5805664	0.0
AP	A	167580.0000000	-913.1589355	-0.0000000
AP	P	-167580.0000000	-1125.6406250	-0.0000000
PN	P	167580.0000000	-898.6037598	0.0000000
PN	N	-167580.0000000	-2048.3959961	49475.5976562
NO	N	167580.0000000	-2907.2189941	-49475.5976562
NO	O	-167580.0000000	-666.5805664	0.0000000

RESULTANT JOINT LOADS - SUPPORTS

JOINT	/------------------- FORCE		---------------//------------------	MOMENT	------------------/
	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	175254.6875000	9641.2382812				0.3988374
E	75138.5625000	-1739.1462402				-0.2248941
G	-75138.5625000	-1739.1621094				0.5150984
K	-175254.7500000	11467.53[illegible]				-0.0000000
L	-0.0052761	2024.2443848				-0.0000000
M	0.0	4955.6132812				-0.0000000
O	0.0	-0.0000000				0.0000000
N	0.0	-4955.6132812				0.0000000
P	0.0052761	-2024.2443848				0.0000000

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	/--------------- DISPLACEMENT		---------------//---------------	ROTATION	------------------/
	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
A	0.0	0.0				0.0154571
E	0.0	0.0				0.0063305
G	0.0	0.0				-0.0063305
K	0.0	0.0				-0.0154570
L	0.0	0.0				0.0007945
M	0.0	0.0				-0.0000370
O	0.0	0.0				-0.0006472
N	0.0	0.0				-0.0000370
P	0.0	0.0				0.0007945

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	/--------------- DISPLACEMENT		---------------//---------------	ROTATION	------------------/
	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
B	-0.9577826	0.6542234				0.0071266
C	-0.8377792	0.7585564				-0.0067244
D	-0.2330315	0.1580546				-0.0087913
F	-0.0000000	0.7448837				-0.0000000
H	0.2330315	0.1580549				0.0087913
I	0.8377788	0.75855[illegible]				0.0067244
J	0.9577822	0.65422[illegible]				-0.0071266

APPENDIX C

GENERAL PURPOSE ARCH RIB ANALYSIS

For general purpose size shelters, using many of the same components used in the hangar, a structural analysis was performed using ICES system of computer programming. Figure C-1 shows the general configuration and loads on such structures. Each arrow indicates the cam-lock load due to 90 mph winds on the arch rib.

The program enclosed indicates the variation of bending moment, axial load and shear force across the span as well as the deformation of the numbered points on the arch.

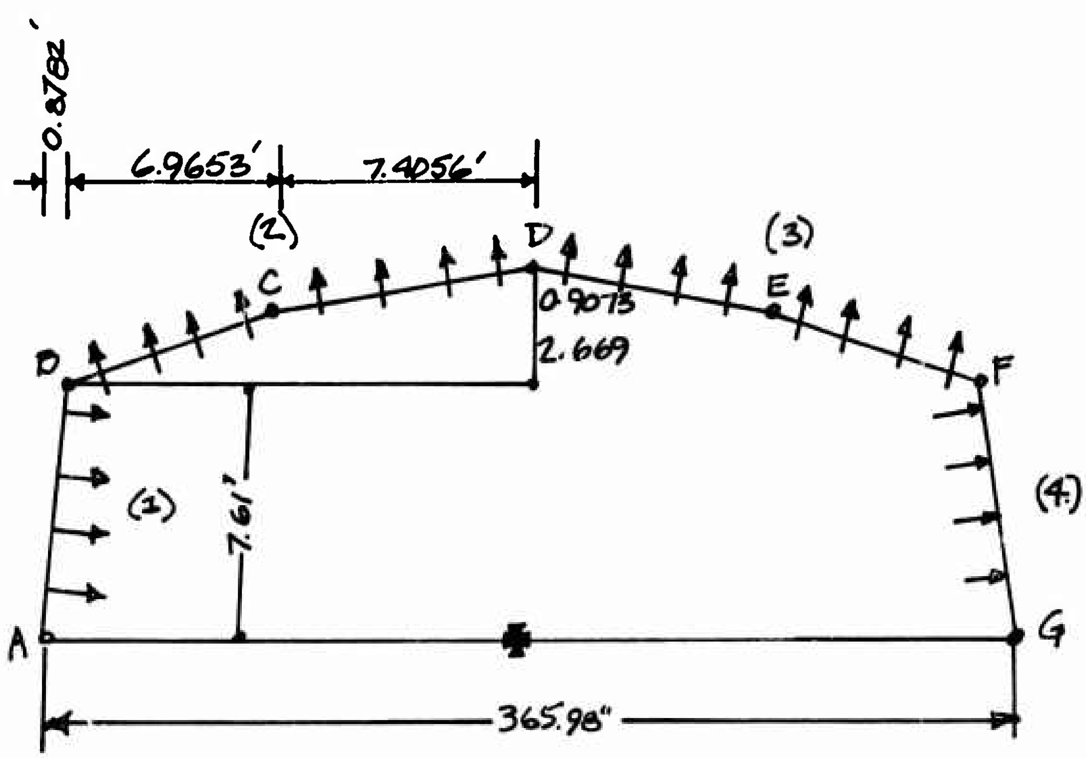


Figure C-1. Arch Loading

A. <u>COMPUTER ANALYSIS</u>

90 mph wind loading on the general purpose shelter structure

```
STRUDL

          ****************************************
          *                                      *
          *            ICES STRUDL-I             *
          *    THE STRUCTURAL DESIGN LANGUAGE    *
          *                                      *
          *  CIVIL ENGINEERING SYSTEMS LABORATORY *
          * MASSACHUSETTS INSTITUTE OF TECHNOLOGY *
          *      CAMBRIDGE, MASSACHUSETTS        *
          *         JUNE, 1968  MOD 2            *
          *                                      *
          ****************************************

TYPE PLANE FRAME
UNITS LB INCH
OUT DEC 2
JOINT COORD
'A' -182.989 0 S
'B' -172.451 91.32
'C' -86.867 123.348
'D' 0 134.238
'E' 86.867 123.348
'F' 172.451 91.32
'G' 182.988 0 S
JOINT 'A' 'G' RELEASE MOM Z
MEMBER INCIDENTS
'AB' 'A' 'B'
'BC' 'B' 'C'
'CD' 'C' 'D'
'DE' 'D' 'E'
'EF' 'E' 'F'
'FG' 'F' 'G'
LOADING 1
MEMBER LOADS
'AB'      FORCE Y CON P -134 L 11.75
'AB'      FORCE Y CON P -134 L 34.25
'AB'      FORCE Y CON P -134 L 56.75
'AB'      FORCE Y CON P -134 L 79.25
```

```
'BC'      FORCE Y CON P 65.2 L 11.75
'BC'      FORCE Y CON P 65.2 L 34.25
'BC'      FORCE Y CON P 65.2 L 56.75
'BC'      FORCE Y CON P 65.2 L 79.25
'CD'      FORCE Y CON P +65.2 L 11.75
'CD'      FORCE Y CON P +65.2 L 34.25
'CD'      FORCE Y CON P +65.2 L 56.75
'CD'      FORCE Y CON P +65.2 L 79.25
'DE'      FORCE Y CON P +96.0 L 11.75
'DE'      FORCE Y CON P +96.0 L 34.25
'DE'      FORCE Y CON P +96.0 L 56.75
'DE'      FORCE Y CON P +96.0 L 79.25
'EF'      FORCE Y CON P +96.0 L 11.75
'EF'      FORCE Y CON P +96.0 L 34.25
'EF'      FORCE Y CON P +96.0 L 56.75
'EF'      FORCE Y CON P +96.0 L 79.25
'FG'      FORCE Y CON P 76.5 L 11.75
'FG'      FORCE Y CON P 76.5 L 34.25
'FG'      FORCE Y CON P 76.5 L 56.75
'FG'      FORCE Y CON P 76.5 L 79.25
MEMBERS 'AB' 'BC' 'CD' 'DE' 'EF' 'FG' PROPERTIES PRISMATIC AX 2.632 IY 13.37 -
IZ 13.37
CONSTANTS E 9800000. ALL
LOADING LIST ALL
STIFFNESS
TIME FOR MODULE STCOMP FOR    6 MEMBERS=     2.71 SECONDS
TIME FOR MODULE STSTDP FOR    6 MEMBERS=     0.78 SECONDS
TIME FOR MODULE STMDDP FOR   24 LOADS=       5.59 SECONDS
TIME FOR MODULE STASDP FOR    6 MEMBERS=     0.64 SECONDS
TIME FOR MODULE STJPDP FOR    7 JOINTS=     0.20 SECONDS
TIME FOR MODULE STSLDP FOR NSOL=     7 IS    0.73 SECONDS
TIME FOR MODULE STD1BS FOR    7 JOINTS EQUALS     0.02 SECONDS
TIME FOR MODULE STD3BS FOR    7 JOINTS EQUALS     0.19 SECONDS
TIME FOR MODULE STBKSB FOR    6 MEMBERS=     5.49 SECONDS
PRINT DATA
```

```
*******************************************
*  PROBLEM DATA FROM INTERNAL STORAGE     *
*******************************************
```

JOB ID NONE NAME -

ACTIVE UNITS	LENGTH	WEIGHT	ANGLE	TEMPERATURE	TIME
	INCH	LB	RAD	DEGF	SEC

********** STRUCTURAL DATA **********

ACTIVE STRUCTURE TYPE - PLANE FRAME

ACTIVE COORDINATE AXES X Y

JOINT COORDINATES					RELEASES					STATUS
JOINT	X	Y	Z	CONDITION	FORCE	MOMENT	THETA 1	THETA 2	THETA 3	
A	-182.989	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE
B	-172.451	91.320	0.0							ACTIVE
C	-88.867	123.348	0.0							ACTIVE
D	0.0	134.238	0.0							ACTIVE
E	88.867	123.348	0.0							ACTIVE
F	172.451	91.320	0.0							ACTIVE
G	182.988	0.0	0.0	SUPPORT		Z	0.0	0.0	0.0	ACTIVE

MEMBER INCIDENCES			LENGTH	RELEASES				STATUS
				START		END		
MEMBER	START	END	LOCAL COORD.	FORCE	MOMENT	FORCE	MOMENT	
AB	A	B	91.926					ACTIVE
BC	B	C	89.510					ACTIVE
CD	C	D	89.532					ACTIVE
DE	D	E	89.532					ACTIVE
EF	E	F	89.510					ACTIVE
FG	F	G	91.926					ACTIVE

MEMBER PROPERTIES											
MEMBER	TYPE/SEG	SEG.L	COMP	AX	AY	AZ	IX	IY	IZ	SY	SZ
AB	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0
BC	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0
CD	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0
DE	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0
EF	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0
FG	PRISMATIC			2.632	0.0	0.0	0.0	13.370	13.370	0.0	0.0

```
MEMBER DEPTH -----------------------------------------------------/
MEMBER                  Y DEPTH       Z DEPTH     Y CENTROID    Z CENTROID

MEMBER CONSTANTS --------------------------------------------------------------/
CONSTANT   STANDARD VALUE   DOMAIN,          VALUE        MEMBER LIST

   E       9800000.000000     ALL

   G               0.0        ALL

DENSITY         1.000000      ALL

   CTE          1.000000      ALL

  BETA             0.0        ALL

        ********** LOADING DATA **********

LOADING LIST    1

LOADING - 1

MEMBER LOADS ------------------------------------------------------------------
MEMBER
AB          CONCEN.   LOAD    FORCE   Y        P   -134.000     L 11.750
            CONCEN.   LOAD    FORCE   Y        P   -134.000     L 34.250
            CONCEN.   LOAD    FORCE   Y        P   -134.000     L 56.750
            CONCEN.   LOAD    FORCE   Y        P   -134.000     L 79.250
BC          CONCEN.   LOAD    FORCE   Y        P     65.200     L 11.750
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 34.250
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 56.750
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 79.250
CD          CONCEN.   LOAD    FORCE   Y        P     65.200     L 11.750
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 34.250
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 56.750
            CONCEN.   LOAD    FORCE   Y        P     65.200     L 79.250
DE          CONCEN.   LOAD    FORCE   Y        P     96.000     L 11.750
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 34.250
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 56.750
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 79.250
EF          CONCEN.   LOAD    FORCE   Y        P     96.000     L 11.750
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 34.250
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 56.750
            CONCEN.   LOAD    FORCE   Y        P     96.000     L 79.250
FG          CONCEN.   LOAD    FORCE   Y        P     76.500     L 11.750
            CONCEN.   LOAD    FORCE   Y        P     76.500     L 34.250
            CONCEN.   LOAD    FORCE   Y        P     76.500     L 56.750
            CONCEN.   LOAD    FORCE   Y        P     76.500     L 79.250

JOINT LOADS-------------------------------/ ------------------------------------/
```

```
JOINT   FORCE X          Y          Z      MOMENT X       Y          Z
JOINT DISPLACEMENTS----------------------/ ---------------------------------/
JOINT   DISP. X          Y          Z      ROT.   X       Y          Z

JOINT FORCE ASSUMPTIONS ------------------------------------------------------------------/
JOINT    THETA  1        2          3    FORCE X         Y          Z      MOMENT X       Y          Z
NO ASSUMPTIONS GIVEN FOR THIS LOADING

MEMBER FORCE ASSUMPTIONS ------------------/   ------------------------------/
MEMBER      COMPONENT  DISTANCE    VALUE        COMPONENT  DISTANCE    VALUE
NO ASSUMPTIONS GIVEN FOR THIS LOADING

****************************************
*  END OF DATA FROM  INTERNAL STORAGE  *
****************************************
```

****
RESULTS OF LATEST ANALYSES
****

PROBLEM - NONE TITLE -

ACTIVE UNITS INCH LB RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

LOADING - 1

MEMBER FORCES

MEMBER	JOINT	/ FORCE			//MOMENT		/
		AXIAL	SHEAR Y	SHEAR Z	TORSIONAL	BENDING Y	BENDING Z
AB	A	-717.10	764.42				-0.02
AB	B	717.10	-228.42				45385.63
BC	B	-534.18	-530.15				-45385.83
BC	C	534.18	269.35				9409.55
CD	C	-453.29	-390.42				-9409.55
CD	D	453.29	129.62				-14062.20
DE	D	-408.58	-235.24				14062.20
DE	E	408.58	-148.76				-18215.39
EF	E	-432.42	45.65				18215.39
EF	F	432.42	-429.65				2770.71
FG	F	-580.93	-184.68				-2770.71
FG	G	580.93	-121.32				-0.00

RESULTANT JOINT LOADS - SUPPORTS

JOINT	/ FORCE			//MOMENT		/
	X FORCE	Y FORCE	Z FORCE	X MOMENT	Y MOMENT	Z MOMENT
A	-841.59	-624.75				-0.02
G	-53.93	-591.00				-0.00

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
	DISPLACEMENT			ROTATION		
A	0.0	0.0				-0.03
G	0.0	0.0				-0.01

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
	DISPLACEMENT			ROTATION		
B	1.77	-0.20				-0.01
C	1.66	0.09				0.01
D	1.56	0.97				0.01
E	1.57	1.04				-0.01
F	1.23	0.14				-0.01

APPENDIX D

COMPONENT STRUCTURAL ANALYSIS

A. HINGE DESIGN

1. Two hinges are used to connect the beams together to form the arch rib.

Max. force on each hinge = F

$$F \times d = M$$

$$F \times 5.6875 = 80758$$

therefore, $F = \underline{\underline{14200 \text{ lbs}}}$

$$\text{Max. stress in the knuckle} = \frac{F}{a} = \frac{14200}{2 \times 2 \times 3/4 \times 0.22}$$

$$= 21550 \text{ psi}$$

Using C-1045 type steel, $f_y = 75000$ psi

therefore, $F.S. = \frac{75000}{21550} = 3.46$ (needed for dynamic loading)

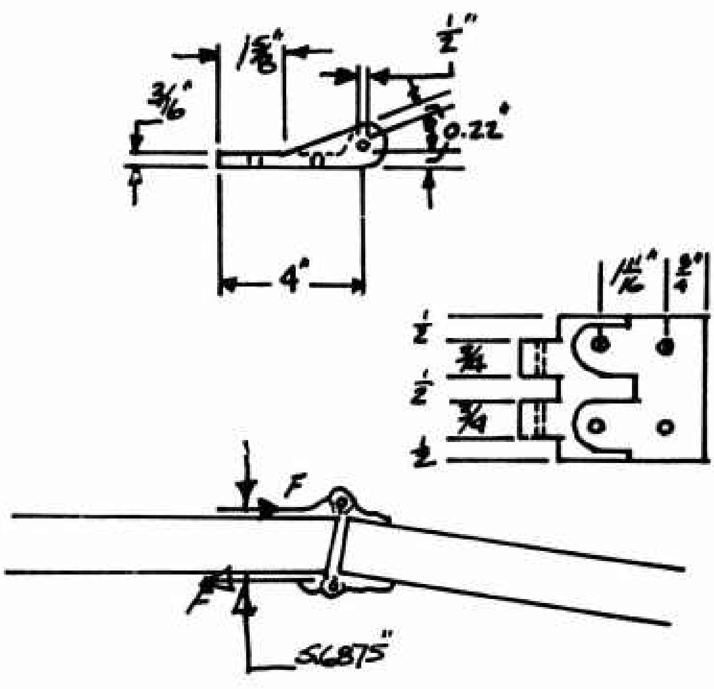


Figure D-1. Hinge Details

2. Hinge to Beam Connection. If 80% of load is taken by front bolts, then the load per bolt is:

$$\frac{14200 \times 80}{2 \times 100} = 5700 \text{ lbs/bolt}$$

Shear stress on 7/16" diam. bolts, Mil AN7-10A,

$$\sigma_s = \frac{5700}{\pi/4 \times (7/16)^2} = 38,000 \text{ psi}$$

Bearing stress on Al beam, $\sigma_b = \dfrac{5700}{7/16 \times 0.27} = 48,250$ psi

allowable σ_b = 56,000 psi

3. Checking Bending Load on the Hinge

Load on hinge, F = 14,200 lbs

Therefore F_x, vertical load on each hinge is

$F_x = F \times \sin 7° = 14,200 \times 0.12187 = 1730.554$ lbs

Moment at section xx, M = F x d

M = 1730.554 x 1.5 = 2600 lb in

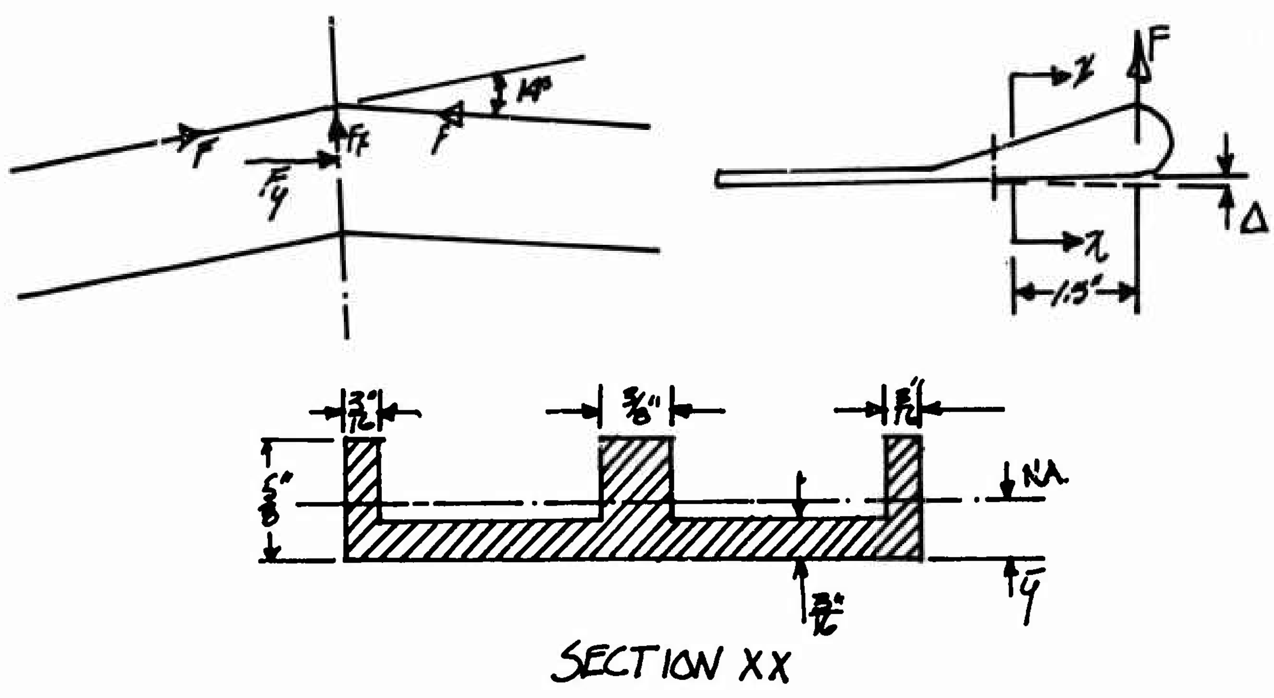


Figure D-2. Bending Load on Hinge

To find $\bar{y}$: $3 \times 3/16 \times 3/32 + 3/4 \times 7/16 \times 13/82 = (57/64)\bar{y}$

$0.05273 + 0.13330 = 0.89062\bar{y}$

therefore, $\bar{y} = 0.20887"$

$$I_{N.A.} = I_{0_1} + I_{0_2} + A_1(d_1)^2 + A_2\ (d_2)^2 =$$

$$\frac{3/4 \times (7/16)^3}{12} + \frac{3 \times (3/16)^3}{12} + \frac{21}{64} \times (0.1972)^2 + \frac{9}{16} \times (0.11512)^2 =$$

$$I_{N.A.} = 0.00523 + 0.002 + 0.01276 + 0.00745 = \underline{\underline{0.02744 \text{ in}^4}}$$

Stress caused in hinge, $\sigma_1 = \frac{M}{I} \times y$

$$= \frac{2600 \times 0.41613}{0.02744}$$

$$= 39429.23 \text{ psi (Axial)}$$

Max. direct stress $= 39429.2 + \frac{14200}{0.89} = \underline{\underline{55429.2 \text{ psi}}}$

Shear stress across hinge is

$$q = \frac{VQ}{Ib} = \frac{1730.55 \times 3/4 \times d \times (d/2)^2}{0.02744 \times 3/4} \approx 1091.05 \text{ psi}$$

where $d = 5/8 - 0.20887 = 0.4111"$

Therefore, Max. principal stress is

$$p_1 = \frac{f_1 + f_2}{2} + \sqrt{(f_1 - f_2/2)^2 + q^2}$$

$$= \frac{55429.2}{2} + \sqrt{(55429.2/2)^2 + (1091.05)^2} = \underline{\underline{55,451 \text{ psi}}} < 75,000$$

Deflection of hinge under <u>bending</u> due to F_x alone is

$$\Delta = \frac{F_x \times (1.5)^3}{3EI} = \frac{1730.5 \times (1.5)^3}{3 \times 30 \times 10^6 \times 0.02744} = \underline{\underline{0.002364"}}$$

Tensile stress on hinge bolts is

$$\sigma_t = \frac{F}{2a} = \frac{1730.5}{2 \times .11039^*} = \underline{\underline{7838.3458}}$$

*Cross section of each bolt

B. BASE PAD DESIGN

1. Due to Wind (90 mph)

$$V = 2317 \times \cos 27° = 2060 \text{ lbs} \uparrow$$

$$H = 2317 \times \sin 27° = 1085 \text{ lbs} \rightarrow$$

Due to Self Weight

$$V^1 = \frac{1800 \text{ (est. wt. of arch)}}{4} = 450 \text{ lbs}$$

therefore, net uplift = $V - V^1$ = $\underline{\underline{1610 \text{ lbs}}}$

$$I_{plate} = 0.009 \text{ in}^4$$

$$M = \frac{w\ell}{4} = 805 \times 9 = 7250 \text{ lb in}$$

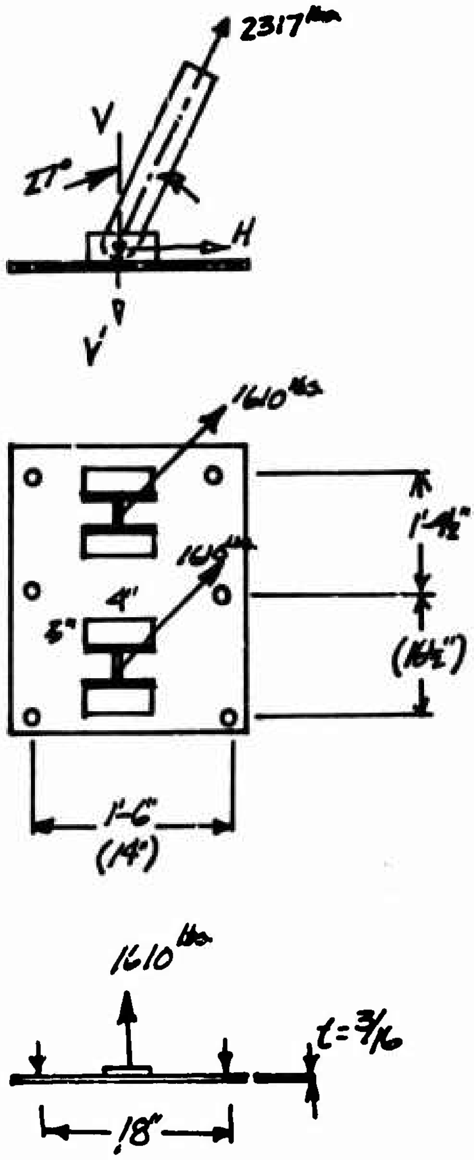


Figure D-3. Base Pad Loading

$$\sigma_b = \frac{M}{I} \times y = \frac{7250}{0.021} \times 3/16 \times 1/2 = \frac{3 \times 7250}{32 \times 0.009} = 75{,}500 \text{ psi (Not adequate)}$$

Using $t = 1/4"$; $I = 0.021$

Therefore, $\sigma_b = \frac{M}{I} \times y = \frac{7250}{0.021} \times 1/8 = 43{,}100 > 35{,}000$ psi
Yield not adequate

If distance between anchoring bolts is reduced to 14" instead of 18", then

$$M = 805 \times 7.0 = 5{,}640 \text{ lb in}$$

Using 1/4" plate, $\sigma_b = \frac{5640}{0.021} \times 1/8 = \underline{\underline{33{,}500 \text{ psi}}}$
Adequate

2. <u>Design of Base Pad Angles and Beam Connection</u>

Axial load due to full snow load, $F = 4152$

Due to self weight, $V' \approx 450$

Therefore, total downward load $\approx$ 4,600 lbs

Max. load on 1/2" bolt = 4,600 lbs.

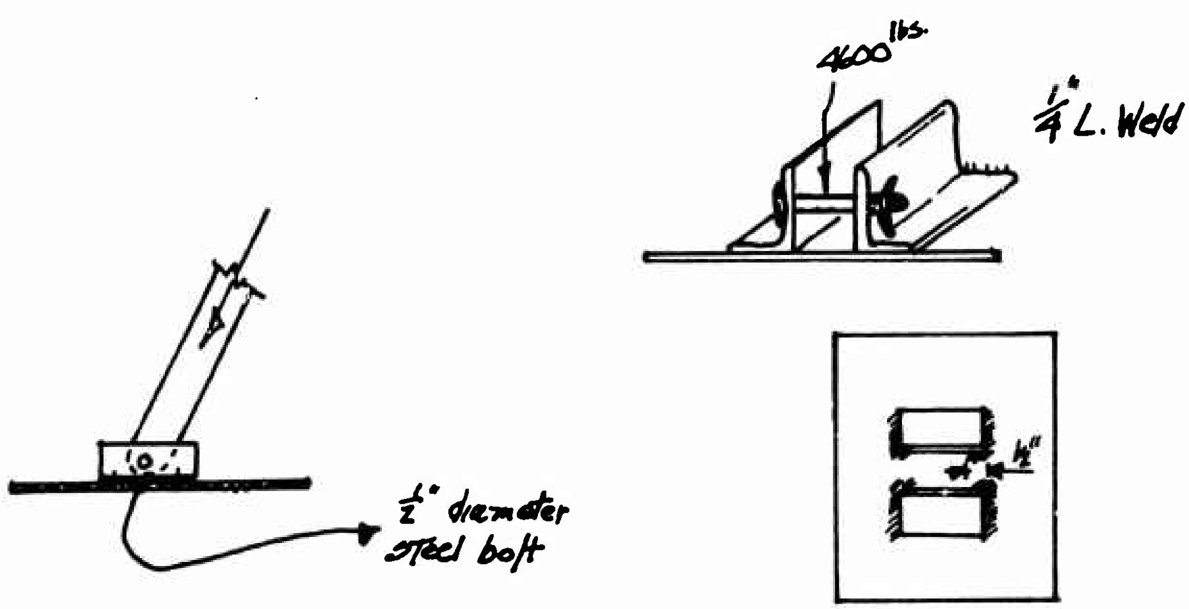


Figure D-4. Base Pad Angles

$$\text{Therefore, } \sigma_b = \frac{F}{2A} = \frac{4600}{2 \times \frac{\pi(1/2)^2}{4}} = \underline{\underline{11,700 \text{ psi}}}$$

Load on each angle is 2,300 lbs

$$\sigma_b = \frac{2300}{1/2 \times 1/4} = 18,400 \text{ psi}$$

4 x 3 x 1/4" Aluminum angles are adequate.

$$\text{Average stress on welds} = \frac{1610}{4 \times 3} = 134 \text{ lbs/in length}$$

C. ARCH RIB END DESIGN

$$I_{web.} = \frac{4.5 \times (1/8 + 1/8 + 0.19)^3}{12}$$

$$= 0.0319 \text{ in}^4$$

$$A = 4.5 \times 0.44 = 1.98$$

$$r = \sqrt{I/A} = \sqrt{0.0319/1.98} = 0.1272$$

$$\frac{KL}{r} = \frac{2.0 \times 2.5}{0.1272} = 39.30$$

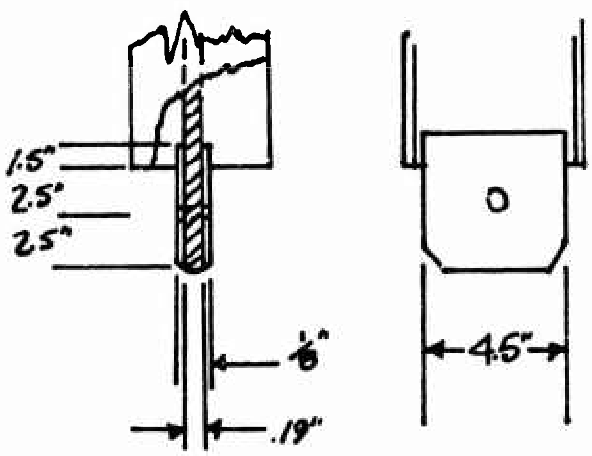


Figure D-5. Arch Rib Web Detail at Base Pad

Therefore, allowable stress $= f_c = B - D\frac{K\ell}{r} = 39.9 - 0.263 \times 39.3$

$= 29.56$ ksi

Therefore, allowable stress $= \frac{4600}{1.98} = \underline{\underline{2,320 \text{ psi}}}$

$$\sigma_b = \frac{4600}{1/2 \times 0.44} = \underline{\underline{20,900 \text{ psi}}}$$

Adequate

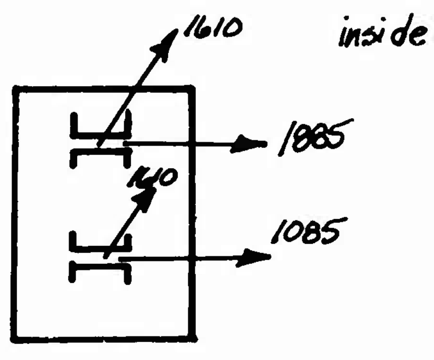
D. LOADING SUMMARY ON BASE PADS (ACTUAL LOADS - POUNDS)

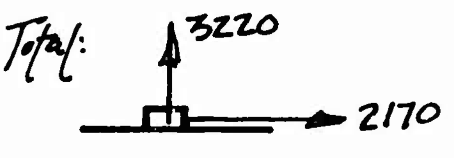
Base pads are secured to the ground by means of six Arrowhead anchors or bolts, whichever is appropriate.

(i) Inner Arches:

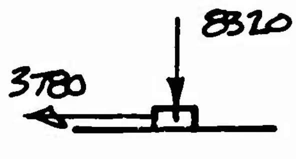
(6 Arrowheads/Base Pad)

(a) Wind





(b) Snow



(ii) End Wall Arch

(a) Wind

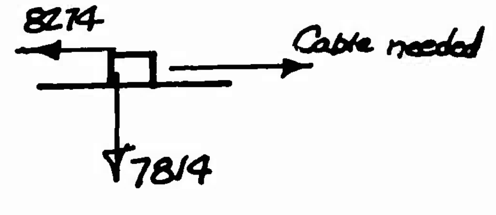


Figure D-6. Summary of Maximum Loads on Base Pads

E. LOAD ON PANEL

1. Camlock Loads

Total load on panel = 666 lbs

Therefore, $P = \frac{666}{4} = \underline{116.5 \text{ lbs}}$ in shear

$$\text{Hence } T = \frac{P}{\text{Sin } \alpha} \simeq \frac{P}{\text{Tan } \alpha} = \frac{166.5}{\frac{1.67}{46\frac{7}{8}}} = \underline{4,780 \text{ lbs}}$$

Tests performed at Wright-Patterson Air Force Base proved that the camlocks withstand loads greater than the above load of 4,780 pounds.

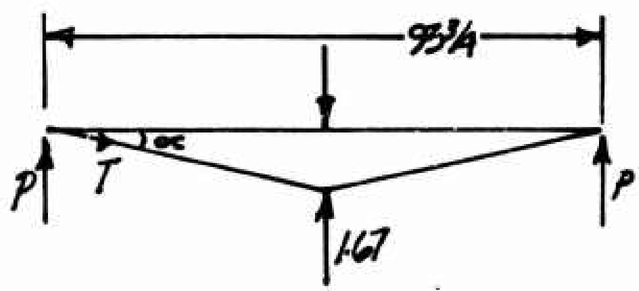


Figure D-7. Load on Panel Camlocks

2. Rigidity of Panels

Deflection of panels is due to bending as well as shear.

$$\text{Hence: } \frac{d^2y}{dx^2} = -\frac{M_x}{EI} + \frac{1}{U}\frac{dV_x}{d_x}$$

Where y = deflection; x = distance along the member; M_x = bending moment at point x; V_x = shear level at point x; EI = flexural rigidity; and U = the shear stiffness.

Solution to the above equation is:

$$y = K_b \times \frac{W\ell^3}{EI} = K_s \times \frac{W\ell}{U}$$

Where K_b = constant due to bending condition, K_s = constant due to shear, K_b was found to be 0.00938 from experimental test analysis which indicates that the manner of attachment of panels to beams is partially a fixed end condition.

$K_s = 1/8, \quad U = 6{,}000^{*}, \quad \ell = 94''$

* For style 125-35, Type 20 (TW)[1]

From Figure D-7, using the slope of the load-deflection lines for different composite materials, EI values for different panels are as follows:

TABLE D-I. EI VALUES FOR DIFFERENT PANEL COMPOSITES

TYPE	MATERIAL		EI LBS IN²
	Skins	Core	
A	0.014" Steel	Paper Honeycomb	10.088×10^4
B	0.032" Al	Paper Honeycomb	8.988×10^4
C	0.032" Al	Balsa Wood	9.000×10^4
D	0.032" Al	Styrofoam	8.230×10^4

$$\text{Theoretical EI for Type C} = \frac{0.0902}{12} \times 10 \times 10^6$$

$$= 7.5 \times 10^4$$

3. Stress in Skin of Panels

Loading: 90 mph wind

Ends are partially fixed, therefore maximum stress which would develop, σ is

$$\sigma = \frac{M}{I} \times y = \frac{\frac{22.2 \times (94)^2}{12 \times 8} \times 3/8}{0.0902} = \underline{\underline{8{,}500 \text{ psi}}}$$

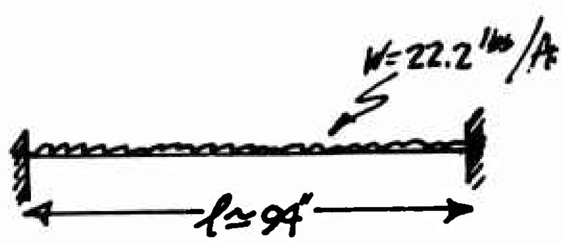


Figure D-8. Panel Loading

[1] Design and Analysis of Sandwich Panels, Aircomb Division of the Douglas Aircraft Company, Inc., p 15.

I value for panels, based on skin only is

$$I/\text{ft. width} = \frac{12}{12}[(0.80)^3 - (0.75)^3]$$

$$= 0.0902 \text{ in}^4/\text{ft width}$$

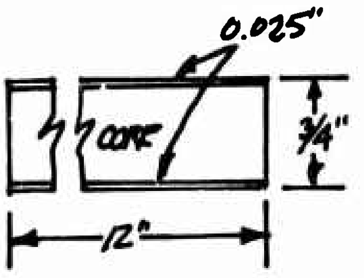


Figure D-9. Panel Section

Type 3004-H32 Aluminum can be used for this purpose.

In practice, stresses are less than 8500 psi, since the core itself contributes to the rigidity of the panels.

4. <u>Shear Stress between Skin and Core</u>

In Section A, $q = \frac{VQ}{Ib}$

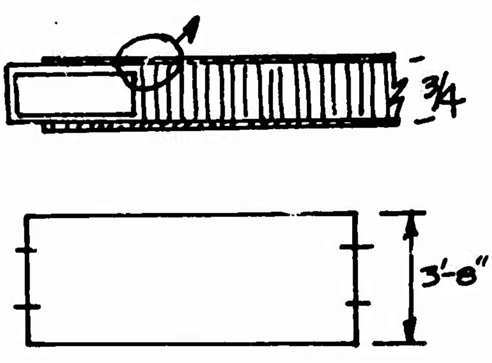


Figure D-10. Panel Detail

Where V = shear load across connecting edge

$$= \frac{666}{2 \times (3'8")} = 7.58 \text{ lbs/in length}$$

Q = static moment of area 1" skin about N.A.

$$= 0.025 \times 1 \times 3/8 = 0.00937$$

b = 1" width under consideration

$$\text{Therefore, } q = \frac{7.58 \times 0.00937}{\frac{0.0902}{12} \times 1} = \underline{\underline{9.45 \text{ psi}}}$$

The above figure is due to bending alone. The shear stress due to 4,780 pounds tension is as follows:

$$s = \frac{4780}{2 \times (3'8")} = \underline{\underline{54.4 \text{ lbs/in width}}}$$

Hence total maximum shear on section A of Figure D-10:

$$\sigma_s = \frac{54.4}{1.4375} + 9.45 = 37.9 + 9.45 = \underline{\underline{47.4 \text{ psi}}}$$

5. <u>Shear Between Panel And Dual Lock Connection</u>

Shear on two 1/4" ϕ rivets = 4,780

$$\text{Therefore, } \sigma_s = \frac{\text{load}}{A} = \frac{4780}{4 \times 0.049} = \underline{\underline{24,000 \text{ psi}}} \text{ across rivets}$$

Bearing stress on edge extrusion:

$$\sigma_b = \frac{4780}{4 \times 1/4 \times 3/32} = 51,000 \text{ psi} < 56,000 \text{ allowable for 6061-T6}$$

Extrusion at open side of panels can be made of 3003-0 Aluminum.

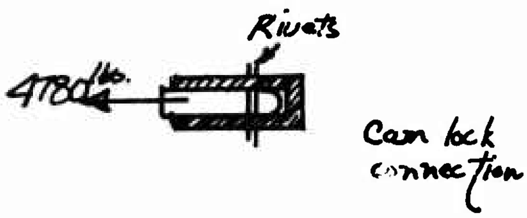


Figure D-11. Camlock Connection

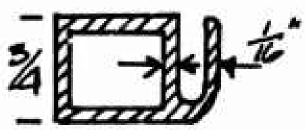


Figure D-12. Edge Extrusion

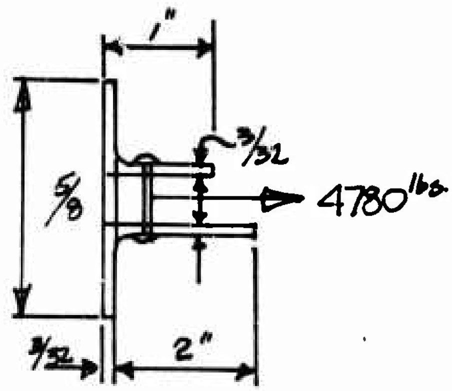
F. <u>CAMLOCK CONNECTION TO ARCH RIBS</u>

Each camlock is secured into the shown extrusion by means of two 1/4 " diameter rivets.

The shear stress capability of the rivets should be

$$\sigma_s > \frac{4780}{2 \times 2 \times 0.049}$$

$$\sigma_s > \underline{\underline{24,000 \text{ psi}}}$$



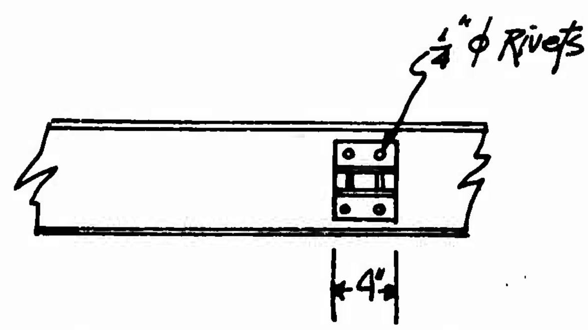


Figure D-13. Camlock Connection to Beam

$$\text{Bearing stress on Al section shown, } \sigma_b = \frac{4780}{4 \times 1/4 \times 3/32}$$

$$= \underline{\underline{51,000 \text{ psi}}}$$

$$\text{allowable } \sigma_b \text{ for 6061-T6} = \underline{\underline{56,000 \text{ psi}}}$$

The rivets which are used to secure the above shown section to arch web should have tensile capability of

$$\sigma_t = \frac{4780}{4 \times 0.049} = \underline{\underline{24,000 \text{ psi}}}$$

G. SPACERS AND CONNECTION

Although each arch is so designed that it acts independently of any other, spacers would transfer the longitudinal loads from one unit to the other. Therefore each spacer should be capable of taking 166 x 2 = <u>332 lbs</u> (Max.)

Two rectangular aluminum tubes slide into each other and bolt assembly A which produces friction between the two which

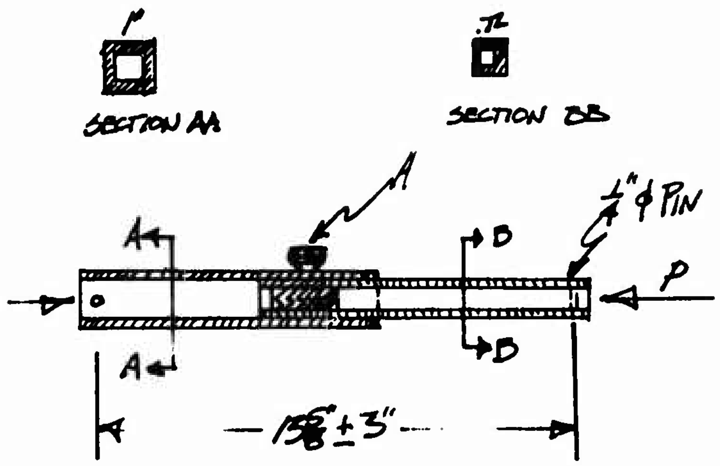


Figure D-14. Spacer Assembly

resists the end load P. Tests at WPAFB showed that if knob A is tool-tightened to 10 ft lb torque (about 90° of turn after hand tightening) the assembly will resist 500 pounds. (Nearly 50% more than the required 332 pounds)

If someone with a weight of 300 pounds walks on these spacers, stresses caused in 1/4" ϕ pins (at end assembly to beams) are far less than allowable (see panel connections and stresses).

Spacers are pinned to two 1" x 1" x 1/8" aluminum angles on the arch beams.

H. OPENABLE FABRIC END WALL

It was decided not to use any vertical columns in the openable end wall. Therefore, all the wind loads on the fabric end wall are transferred to the arch rib and ground beam via nylon webbing and snap hooks. A wind of 90 mph velocity, blowing directly into the end wall produces a dynamic load intensity.

$$q = 0.00256V^2 = 20.74 \text{ lbs/ft}^2$$

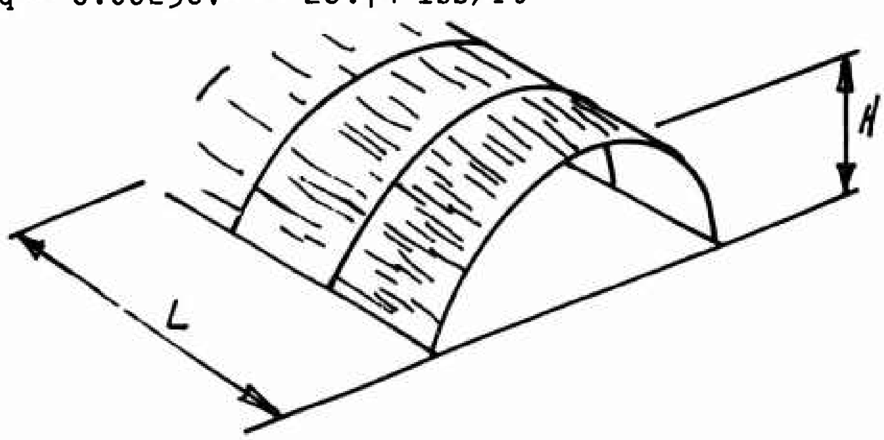


Figure D-15. H/L Diagram

For H/L ratio of 20.5/74.1 = 0.278, static load distribution, w, is as follows:

$$w = C_d \times q = 0.7 \times 20.74 = 14.5 \text{ lbs/ft}^2$$

The general configuration of the end wall is shown in Figure D-16. Because there is a vertical dart provided in the fabric, it is assumed that all loads are transferred to the ribs by vertical tension in the fabric. Typical tension relationship in the fabric is as follows:

$$T = \frac{w\ell}{2}\sqrt{1 + \ell^2/16h^2}$$

where: w = wind pressure, 14.5 lbs/ft^2

ℓ = vertical height of fabric

h = sag needed in fabric

T = load, lbs/ft width of fabric

The intensity of loading on the arch rib and the ground beam, as determined from the equation, is shown in Table D-II.

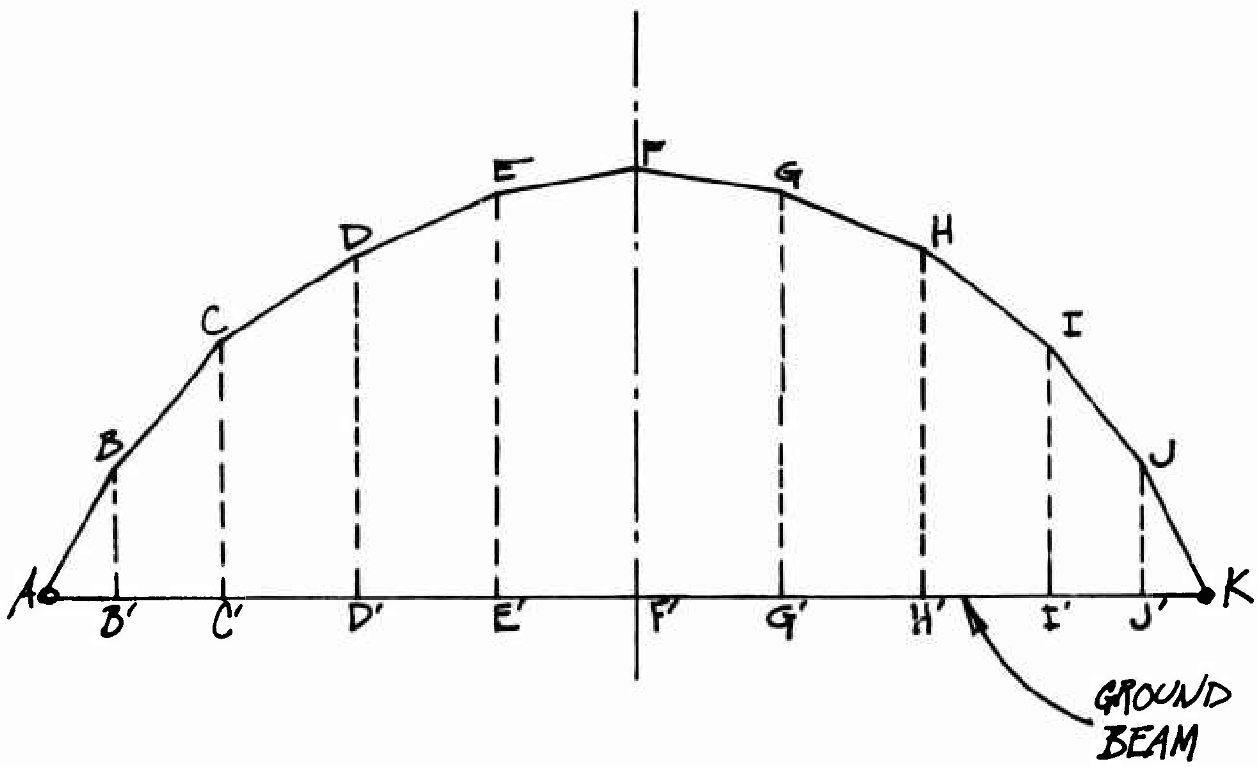


Figure D-16. General Configuration of Openable End Wall

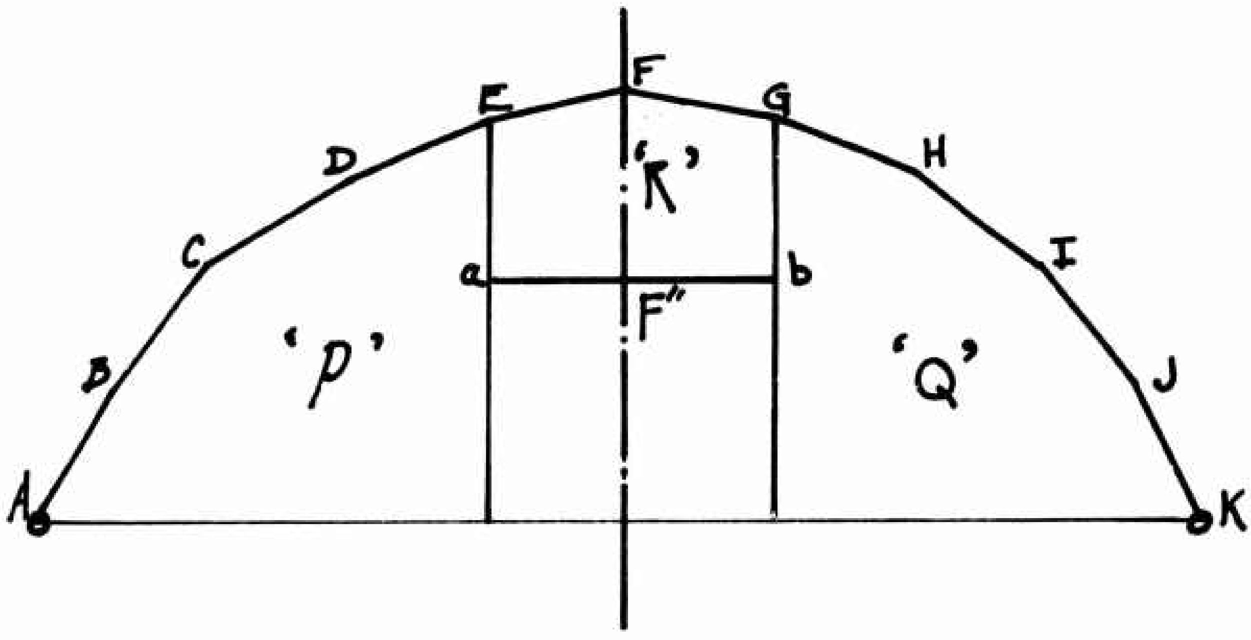


Figure D-17. General Configuration of Fixed Fabric End Wall

With the above load intensities on the structure, a computer structural analysis was run and maximum bending moment, M, and deflection, Δ, on the arch were found to be:

$$M = 250{,}000 \text{ lb in. in arch rib}$$

$$\Delta = \frac{2.79}{83.0} \times 108.5 = \underline{\underline{3.6356''\pm}} \text{ in mid arch}$$

For further details see Appendix B.

It was decided that an 8" x 6.5" x 8.492 pounds per linear foot aluminum wide flange beam be used for the arch rib which carries the fabric and the 5.5" x 3" x 3.09 lbs per linear foot beam for the other rib.

$$\sigma_{b_{max.}} = \frac{M}{I} \times y$$

$$= \frac{250{,}000}{83.0} \times 4$$

$$= \underline{\underline{12{,}048.2 \text{ psi}}}$$

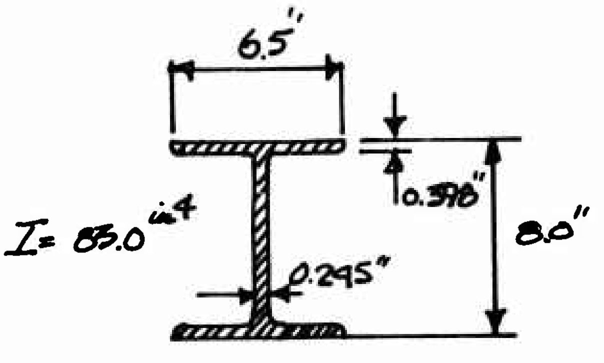


Figure D-18. Beam Section

A hinge is used on each side of the above beam. Therefore,

load/hinge = $\frac{250,000}{8.5 \times 2}$ = $\underline{\underline{14,705 \text{ lbs}}}$ (due to bending)

TABLE D-II. LOAD DISTRIBUTION ACROSS FABRIC END WALL

	BB'	CC'	DD'	EE'	FF'	FF" (Open E. W.)
ℓ. ft.	6.15	11.74	15.97	18.62	19.52	11.0
$\sqrt{1 + \ell^2/h^2}$	3.4	3.4	3.4	3.4	3.4	3.4
h_1 inch	6.00	11.263	15.233	17.540	18.463	10.15
$\frac{w\ell}{2}$	47.13	88.45	119.62	137.75	145.	79.75
T lbs/ft	160.225	300.73	406.72	468.00	493.00	271.15

Maximum axial load on arch = 13177.4 lbs

load/hinge = $\frac{13177.4}{4}$ = $\underline{\underline{3294.35 \text{ lbs}}}$

Hence, maximum load/hinge

F_{total} = -(14705 + 3294.35) = -17999.35 ≃ -18,000 lbs

maximum stress caused = $\frac{18,000}{0.66}$ = 27272.72 psi
< 75,000 allowable

Maximum load on snap hooks

maximum tension in fabric = 505 lbs/ft width

load on each fabric connection, P_L = 505 x $\frac{10"}{12}$ = $\underline{\underline{420.83 \text{ lbs}}}$

(Note: 10" is maximum distance between connections)

Fabric length: With sags needed in fabric (Table D-II), the overall length of fabric is worked out using the following relationship:

$$S = \ell[1 + \frac{8}{3}[\frac{h}{\ell}]^2 - \frac{32}{5}[\frac{h}{\ell}]^4]$$

where S = length of fabric

ℓ = vertical height of fabric

h = sag in the fabric

Considering the tolerances required to the nearest ±1/2" the ℓ and S dimensions for the selected sections are shown in Figure D-19.

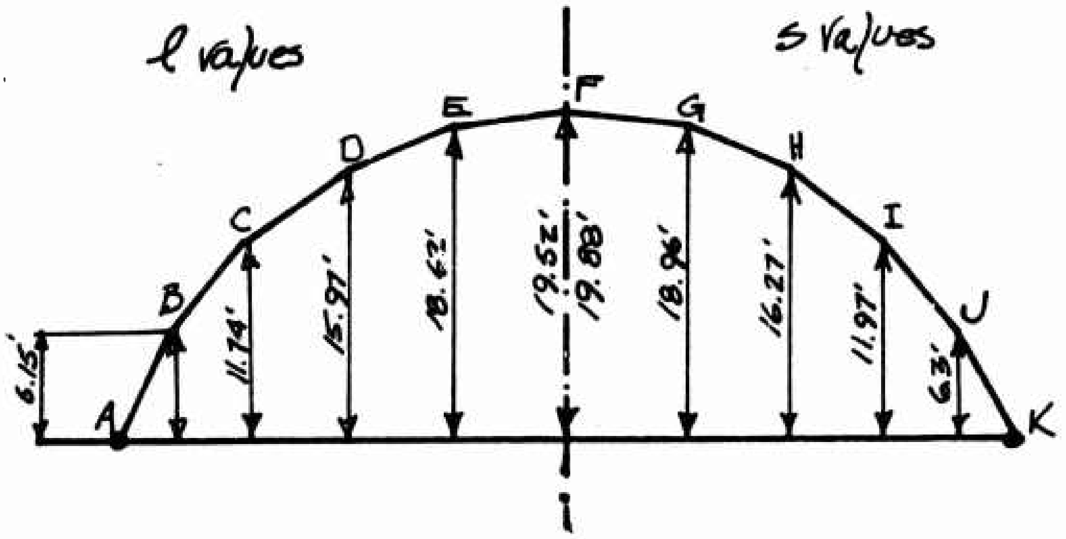


Figure D-19. Fabric Dimensions

I. FIXED FABRIC END WALL

1. The loading on fabrics used in sections P and Q (Figure D-17) are practically the same as openable end wall. For section R, loading on cross beam 'ab' is:

$$271.5 \times 9 = 2440.35 \text{ lbs}$$

Deflection in mid span of 'ab' is:

$$\Delta \text{ ab} = \frac{5}{384} \frac{W\ell^3}{EI}$$

The standard 5.5 x 3" I beam is used, hence

$$\Delta = \frac{5 \times 2440.35 \times (11 \times 12)^3}{384 \times 10 \times 10^6 \times 13.37} = \underline{\underline{0.267" < \text{allowable}}}$$

2. Load on door side columns: (Worst Case)

493 lbs x 9'6" on 20' col. = $\underline{\underline{4683.6 \text{ lbs}}}$

Allowable load on such a column:

$$P_{cr} = \frac{\pi^2 EI}{(20 \times 12)^2} = \underline{8310.85 \text{ lbs} > 4683.6}$$

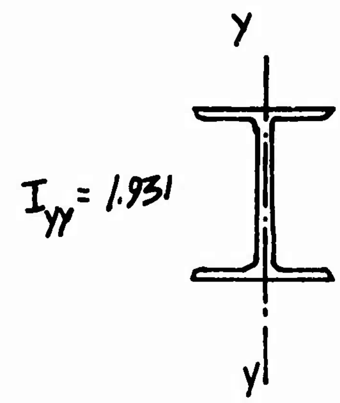


Figure D-20. Beam Section

J. GROUND BEAMS FOR END WALLS

The critical unsupported section shown, AB, has length of 168". Total load on beam AB = 4544.5 lbs.

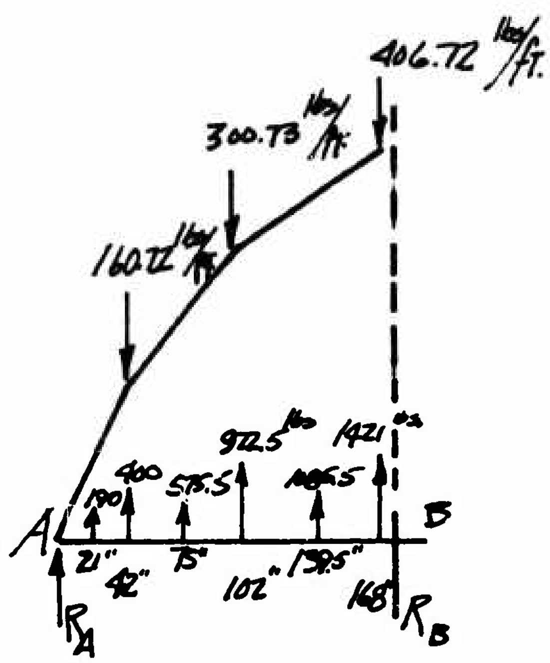


Figure D-21. End Wall Loading

Intensity of load distribution, k, is

$$k = \frac{4544.5}{1421 \times 168/2} = \underline{\underline{0.038}}$$

$$\text{Therefore, } R = \frac{4544.5}{3} = \underline{\underline{1514.83 \text{ lbs}}}$$

$$R_B = \underline{\underline{3029.66 \text{ lbs}}}$$

Maximum deflection, Δ, using standard 5.5" x 3" I beam is

$$\Delta_{max.} = 0.01304 \frac{W\ell^3}{EI}$$

$$= \frac{0.01304 \times 4544.4 \times (168)^3}{10 \times 10^6 \times 13.37}$$

$$= 2.102'' \text{ @ } 0.5193\ell \text{ or } \underline{\underline{87.24'' \text{ from A}}}$$

$$M_{max} = \frac{2\ W\ell}{9\sqrt{3}} = 97956.89 \text{ lb in}$$

Hence, $\sigma_b = \frac{M}{I} \times y = 20148.2 < 25{,}000$ psi allowable working stress

The ground beam is secured to the floor at intervals. The reactions due to wind on the end wall extracted from computer analysis is shown in Figure D-22, considering the self weight of the structure as well as temperature variation.

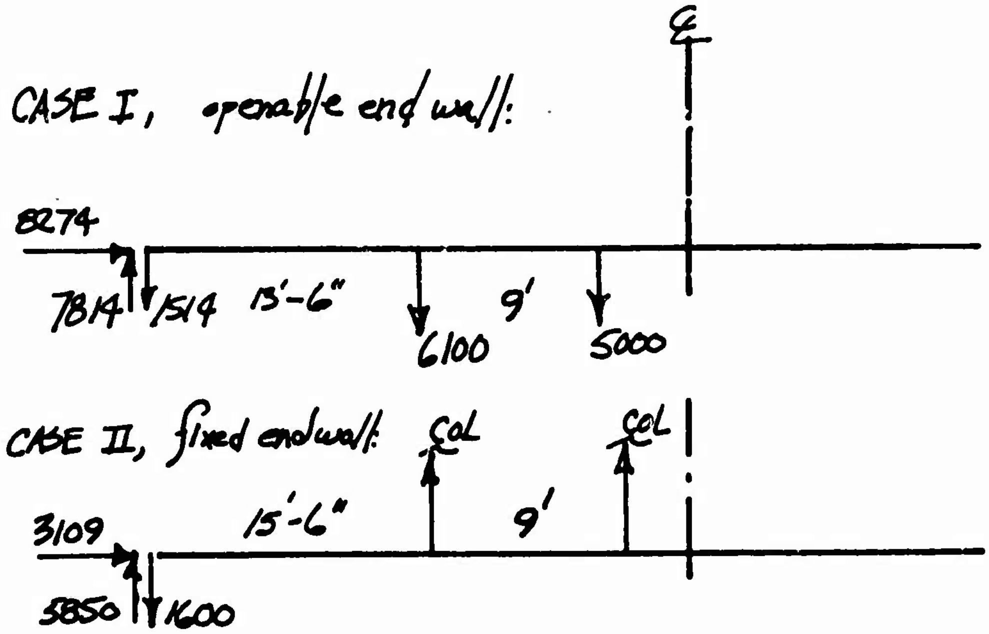


Figure D-22. Anchoring Load at End Walls

K. ARCH RIB TO BASE PAD CONNECTION

Maximum axial load, F = 13177.5 lbs. Therefore, shear stress across 1" diameter bolt, σ_s, is:

$$\sigma_s = \frac{13177.5}{2 \times \pi \times \frac{(0.875)^2}{4}} = 10962.98 \text{ psi} < 13{,}000 \text{ allowable}$$

3/8" thick angles are used to transfer load to base pads. Hence, bearing stress, σ_b, on aluminum angles would be:

$$\sigma_b = \frac{13177.5}{1'' \times 3/8 \times 2} = 17{,}570 \text{ psi} < 20{,}000 \text{ allowable}$$

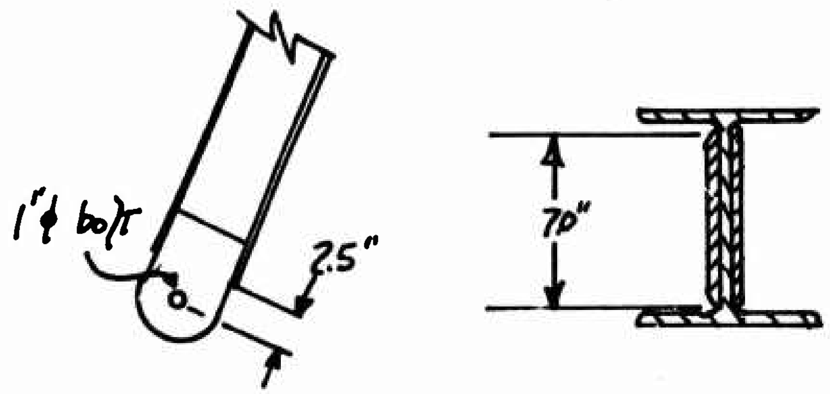


Figure D-23. Beam Web Reinforcing

Web buckling: Two 1/8" plates are welded at either side of 0.245" thick web.

$$I = \frac{7.0 \times (0.495)^3}{12} = 0.070 \text{ in}^4$$

Cross section, A = 7.0 x 0.495 = 3.465 in²

$$r = \sqrt{I/A} = \sqrt{0.020} = 0.1413$$

$$\frac{KL}{r} = \frac{1. \times 2.5''}{0.1413} = 17.692$$

Hence, allowable $f_c = \frac{102000}{(KL/r)^2} = 325.8$ ksi

$$\text{actual } f = \frac{13177.5}{3.465} = \underline{\underline{3803.03 \text{ psi}}}$$

3/8" thick aluminum plate is used for base pads. Two 3/8" angles which transfer load from arch rib to base pad are welded by means of 1/8" aluminum weld. The maximum stress across this weld would be:

$$\sigma_w \quad \frac{8500/2}{(2 \times 3 + 6.25)\ 1/8} = 2775.96 \text{ psi} < \text{allowable}$$

(throat thickness)

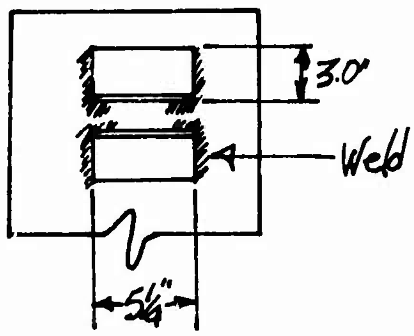


Figure D-24. Base Pad Angle Detail

L. ERECTION OF OPENABLE END WALL ARCH

The arch containing the end wall consists of two arch ribs plus panels and accessories. One arch rib is 5.5" x 3" x 3.09 lbs. size and the other 8" x 6.5" x 8.492 lbs. The weight analysis and consequent reactions due to self weight of arch are as follows:

WEIGHTS/ARCH

Double	Panel Assembly	10 x 160 lbs.	=	1600.0 lbs
Ribs:	Light rib	80 x 3.09	=	247.2
	Hinges	2 x 9 x 3.5*	=	63.0
	Heavy rib	80 x 8.492	=	679.4
	Hinges	4 x 9 x 3.5	=	126.0
Fabric	and Accessories		=	300.0
				3015 ≈ 3000

Weight of half arch (one rib + 1/2 panel) light rib = 1252.7

heavy rib = 1747.3

*Include hinge plus 8 bolts and nuts.

Horizontal reactions due to self-weight: Height to span ratio of arch, $h/\ell = 0.355$. The influence line diagram for horizontal reaction is shown in Figure D-25 for the above ratio.[1] The square scale is 1/20 x 1 x 0.05 P. Area under influence line diagram between hinge locations is measured and multiplied by unit weight of member.

$A_1 = 1.6$ unit squares	$H_1 = 7.9407$
$A_2 = 5.866$	$H_2 = 21.7449$
$A_3 = 13.6$	$H_3 = 40.430$
$A_4 = 20.0$	$H_4 = 52.1958$
$A_5 = 24.53$	$H_5 = 60.1378$

$$\text{load/zone} = \begin{matrix} \dfrac{1252.7}{10} \text{ light} \\[2ex] \dfrac{1747.3}{10} \text{ heavy} \end{matrix}$$

Horizontal reaction for light rib, H_L:

$$H_L = \Sigma[H_1 + H_2 + H_3 + H_4 + H_5] \times 2 = 364.899 \text{ lbs}$$

Similarly, H_H, horizontal reaction for heavy beam:

(See figure D-26) $H_H = 509.2267$ lbs

M. <u>RIGID END WALL DESIGN</u>:

A rigid end wall consisting of many of the same components as the hangar, i.e. beams and panels, was investigated, designed, and one prototype was built. It was composed of vertical columns with standard panels used for the arches as infills. The end wall is shown in Figure 173. The end wall was designed for 90 mph continuous wind loading blowing longitudinally into the end wall as shown in Figure D-27.

$$r = h/\ell = \frac{20'6''}{74'1''} \simeq 0.278$$

Consider 1' strip of loading, $q = 20.7 \text{ lb/ft}^2$. To find load on the arch rib and consequently on panels:

$$R_2 \times 20 = 0.4q \times \frac{20^2}{2} + 0.6q \times \frac{20^2}{6}$$

$$= 120q = 2{,}480$$

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[1]Armco Multiple Plate Design Manual, Armco Railroad Sales Company, p.117.

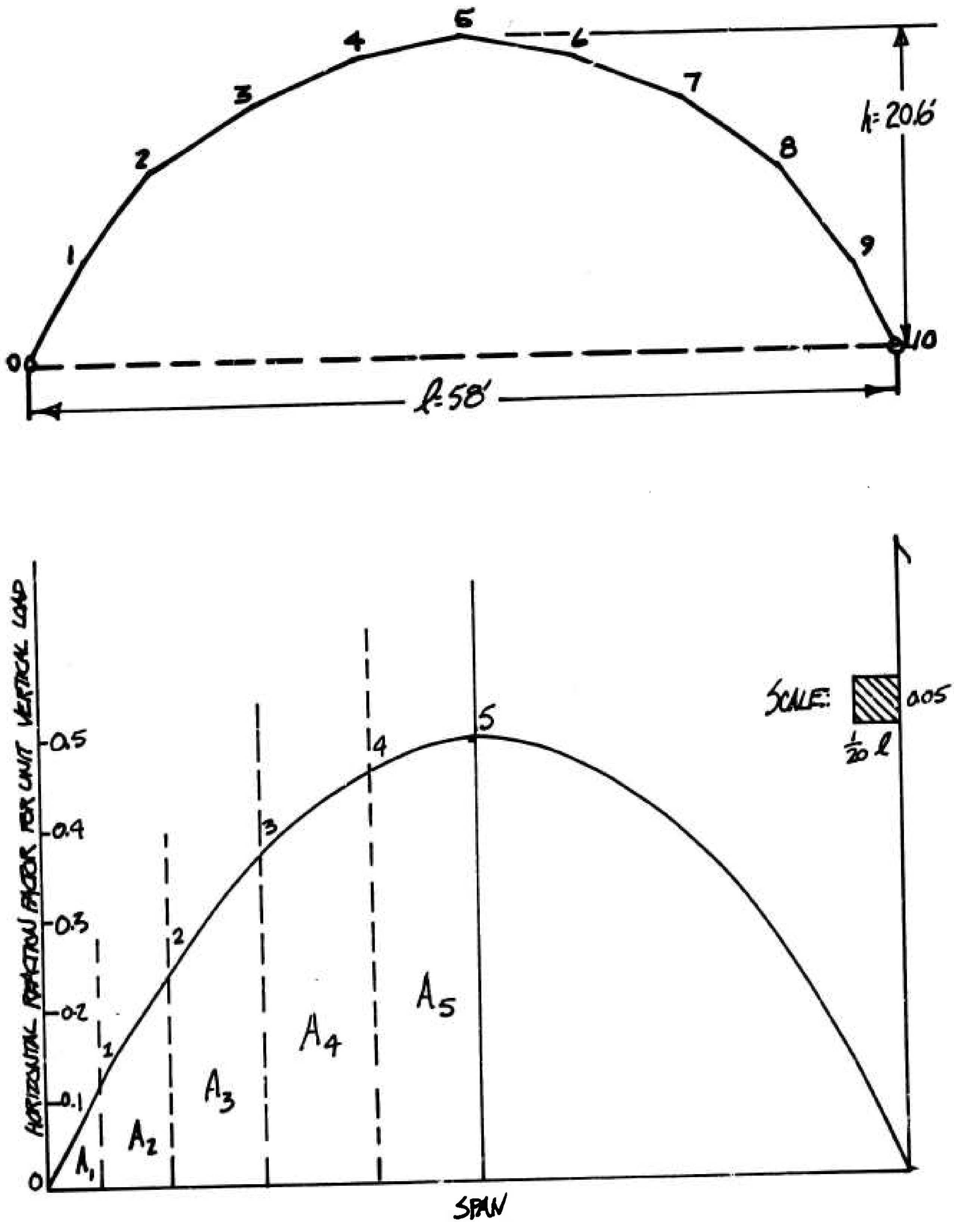
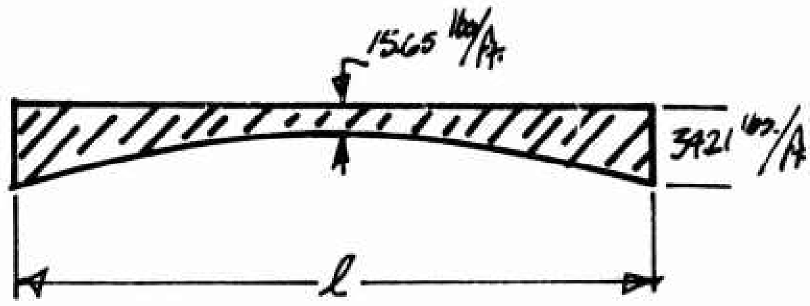


Figure D-25. Influence Diagram for Horizontal Reaction



VERTICAL INTENSITY OF LOADING FOR SELF WEIGHT OF LIGHT RIB.

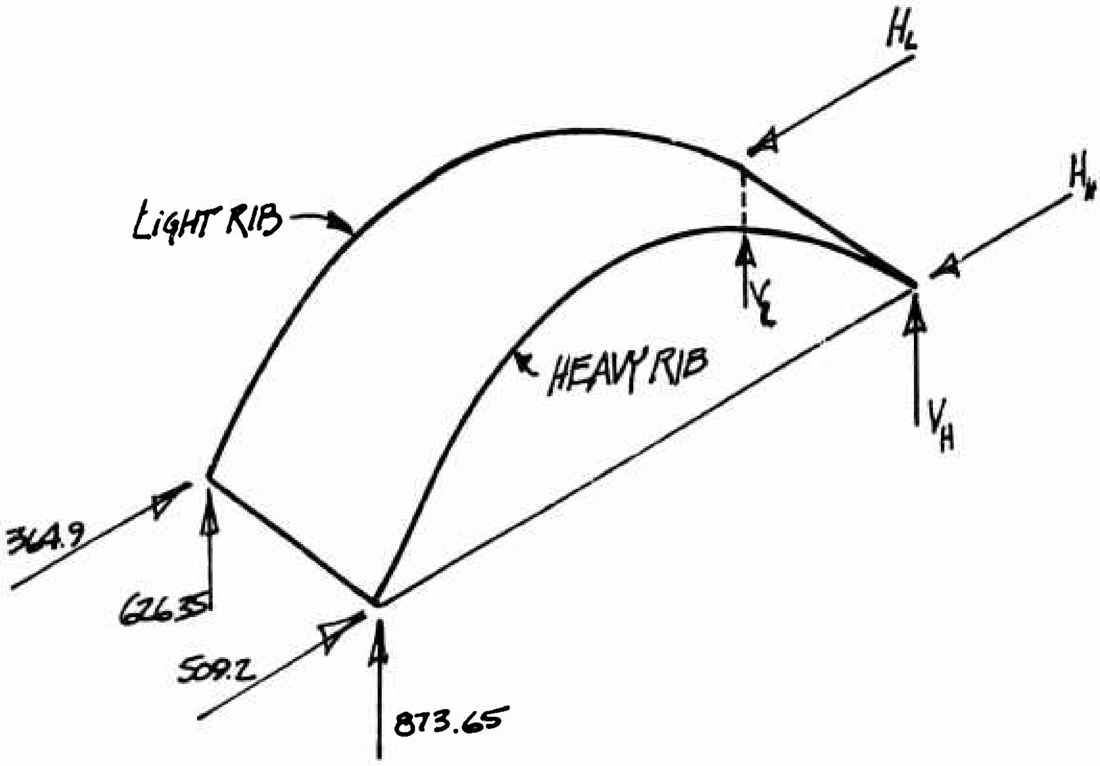


Figure D-26. Reactions in Erection Process of End Wall Arch

To find maximum moment:

$$\frac{k}{1.0} = \frac{13.32 + x}{33.32}$$

$$M_x = R_2 \times x - 0.4q\,\frac{x^2}{2} - \frac{x}{33.32} \times q\,\frac{x^2}{6} = R_2x - 4.14x^2 - 0.1035x^3$$

$\frac{\delta}{\delta} = 0$ at Maximum moment, hence

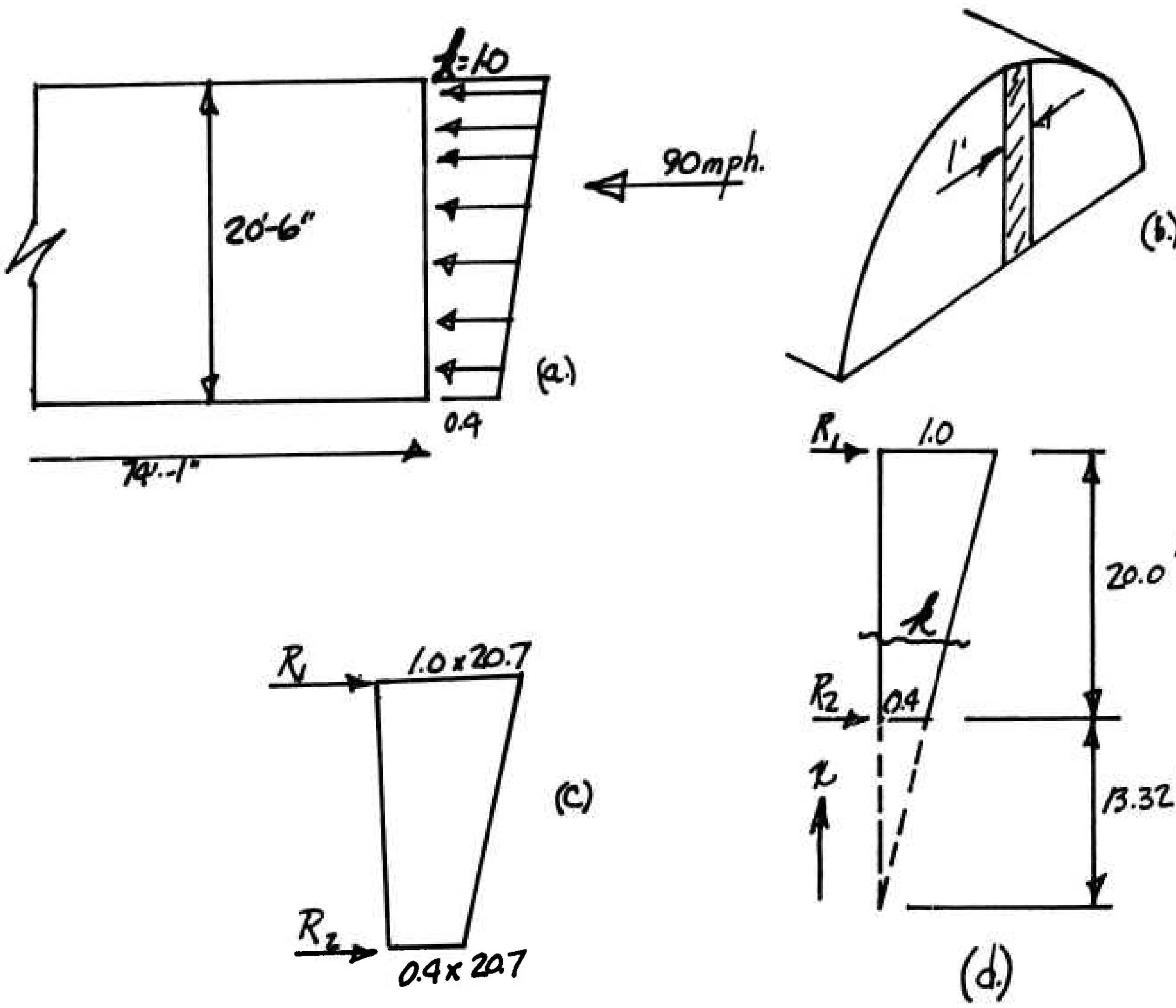


Figure D-27. Wind Loading on End Wall

$$\frac{dM}{dx} = R_2 - 4.14 \times 2x - 0.1035 \times 3x^2$$

$$0.311x^2 + 8.28x - 124 = 0$$

$$x^2 + 26.6x - 398.5 = 0$$

$$x = \frac{-26.6 \pm\sqrt{(26.6)^2 + 1594}}{2} = -37.4,\ \underline{\underline{10.65'}}$$

Therefore, M_{max} $= 124 \times 10.65 - 469 - 124.5$

$= 726.5$ lb ft/ft

OR $= \underline{\underline{8720 \text{ lb in/ft}}}$

Maximum distance between two parallel columns on the fixed fabric end wall is 10'8". Hence, M_{max} on each column is

$$= 8720 \times \frac{10'8''}{2}$$

$$= \underline{\underline{46,500 \text{ lb in/col}}}$$

Using standard I beam which is used for arch ribs,

$$\sigma = \frac{M}{I} \times y = \frac{46500}{13.37} \times 2.75 = 9,560 \text{ psi}$$

Resulting end load on each panel (three panels are involved),

$$P = R_1 \times \frac{10'8''}{3}$$

$$= 166 \times \frac{10.66}{3}$$

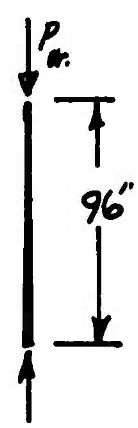
$$= \underline{\underline{590 \text{ lbs}}}$$

Tests showed that the panels are capable of taking 6,000 pounds in compression loading.

Theoretical allowable load on panels (column loading):

$$P_{cr} = f_c \times A$$

$$\text{where } f_c = \frac{102,000}{(k\ell/r)^2} \text{ ksi}$$



$$\frac{k\ell}{r} = \frac{1.0 \times 96''}{\sqrt{I/A}} = \frac{96}{\sqrt{\dfrac{0.0902 \times 3.6}{2 \times 0.025 \times 12 \times 3.66^{*}}}} = \frac{96}{0.388} = 247$$

*Width of panel, 3'8"

$$\text{Therefore, } f_c = \frac{102000}{(247)^2} = 1.67 \text{ ksi}$$

$$\text{Total allowable load, } P_{cr} = 1.67 \times 0.025 \times 2 \times 3.66$$

$$= 3.6 \text{ Kips or } \underline{3,600 \text{ lbs}}$$

The weight of this end wall and erection time involved was beyond acceptable limits. Therefore, the fabric end wall was adopted.

N. COUNTER FLASHING DESIGN

Combination of 1/4" plywood and fabric was used to cover the space between two arch ribs, embracing the ribs. Two 3/16" steel cables, passed through eye-fittings mounted on each side of counter flashing are used to hold the counter flashing on the structure by clamping them down on the base pads.

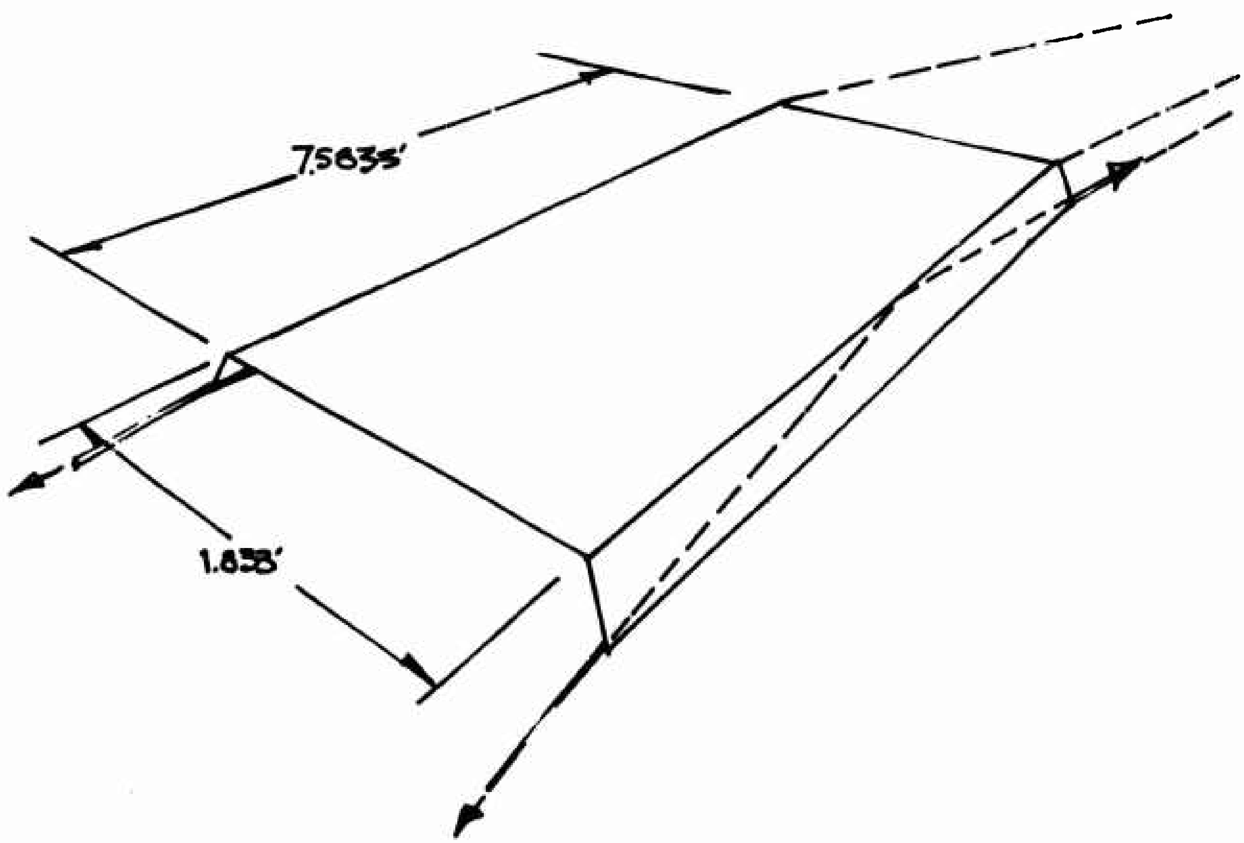


Figure D-28. Counter Flashing Cable

1. <u>Counter Flashing Load</u>

Size of each panel: 7.5833' length
1.833' width

Length of zone: (1) ℓ_1 = 0.4884R
= 14.945'
(2) ℓ_2 = 1.4653R
= 44.8382'
(3) ℓ_3 = 14.945'

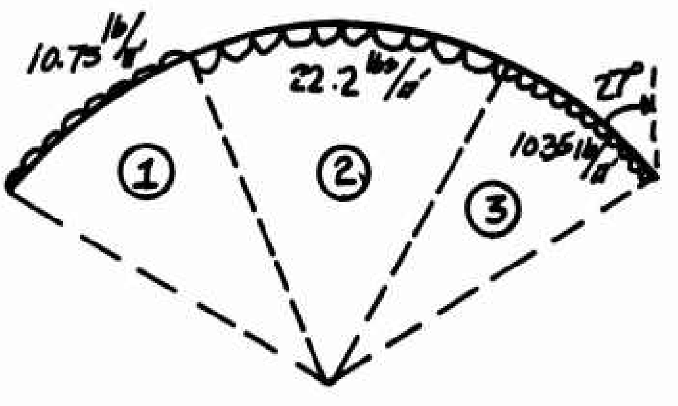


Figure D-29. Counter Flashing Loading

Intensity of loading per foot length:
in Zone (1) = 10.75 x 1.833 = 19705 pressure
in Zone (2) = 22.2 x 1.833 = 40.69/lb ft suction
in Zone (3) = 10.35 x 1.833 = 18.972 suction

Total load on counter flashing in form of suction:
$40.69\ell_2 + 18.97\ell_3 = 2108.003$ pounds

Since the form of cable is restrained and governed by the arch, tension, T = v/cos α. Therefore, tension in cables to hold counter flashing down:

$$T = \frac{2108}{2} \times \frac{1}{\cos 27°} = \frac{2108}{2 \times 0.981}$$

$$= 1182.94 \text{ lbs/counter flashing}$$

Since there are two cables used per counter flashing,

$$\text{max. load/ cable} = \frac{1182.94}{2} = \underline{\underline{591.47 \text{ lbs}}}$$

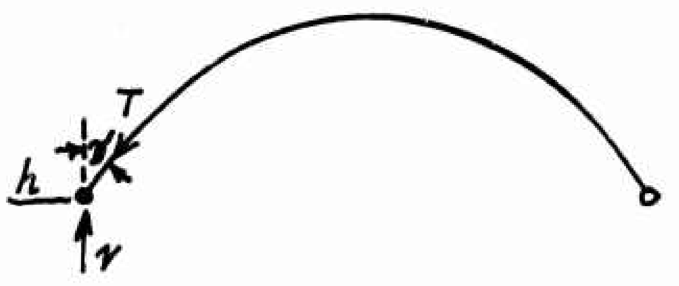


Figure D-30. Angle of Tension Cable with Base Pad

2. <u>Load on Counter Flashing Panels</u>

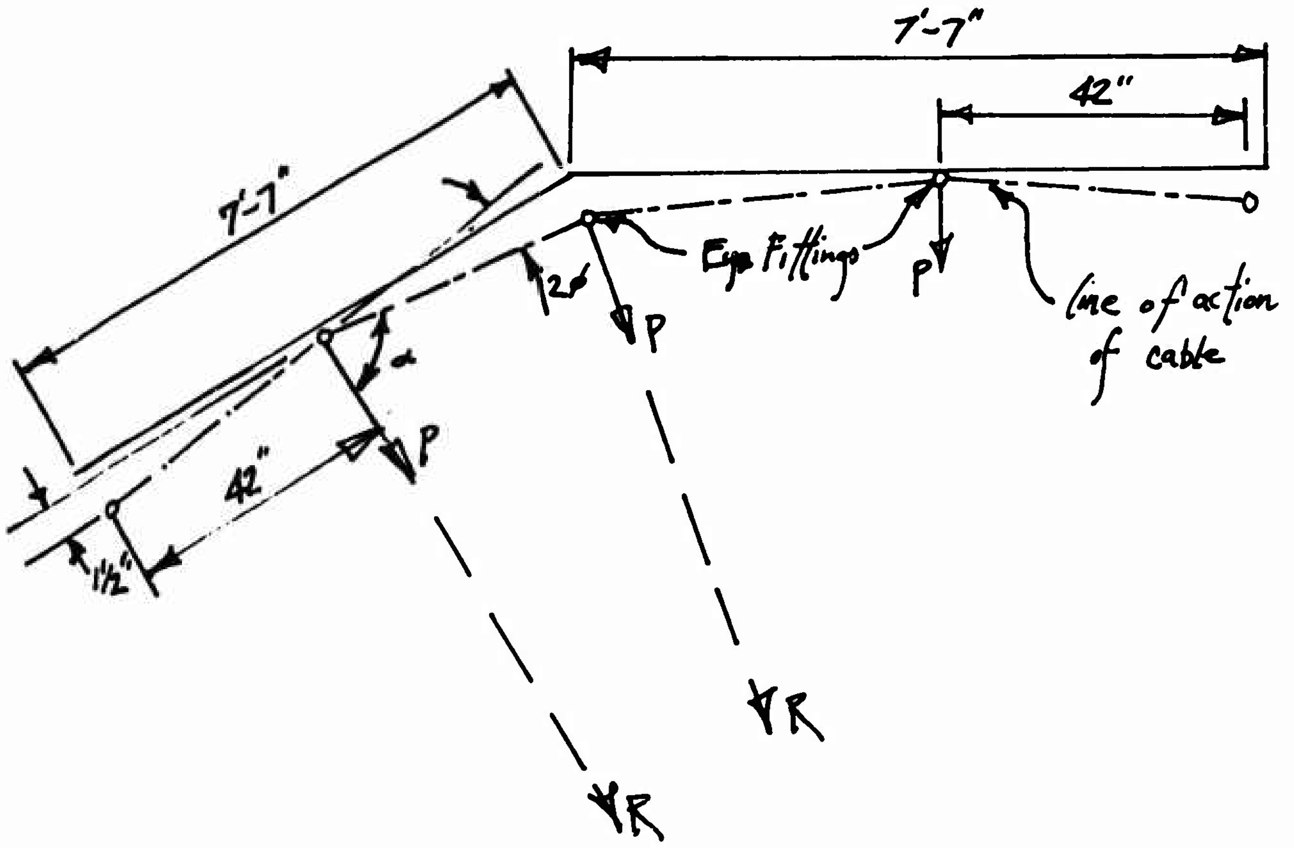


Figure D-31. Load on Counter Flashing Panels

$$\phi = \tan^{-1} \frac{1.5}{42} = 0.0357^{\text{Rad}} = 2.0464°$$

Therefore, $2\phi = 4.0928° = \underline{4°5'35''}$

Hence, $\alpha = 90 - \phi = \underline{\underline{87°57'13''}}$

Pull down force, P, on eye-fittings:

$$P = 2\ T \cos 87°57'13"$$

$$= 2 \times 591.47 \times 0.05153$$

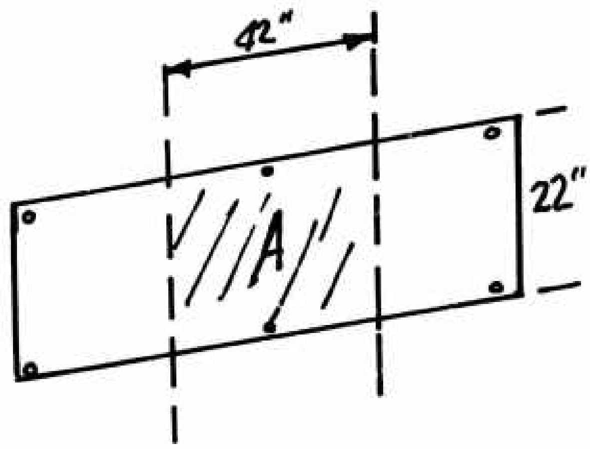
$$= \underline{\underline{60.0569\ \text{lbs}}}$$

Maximum load/eye-fitting due to suction:

$$A \times \frac{22.2\ \text{lbs/ft}^2}{2} = \frac{1.8 \times \frac{42}{12} \times 22.2}{2}$$

$$= \underline{\underline{71.6\ \text{lbs}}}$$

Therefore, eye-fittings load capacity > $\underline{\underline{72\ \text{lbs}}}$



Length of cables for counter flashings:

		Actual Total Length	Length of Steel Cable	Seat Belts Length
(i)	Hangar	75'10" + (2 x 4")	73'6"	2 x (1'6")
(ii)	Utility	45'6" + (2 x 4")	43'2"	2 x (1'6")

O. COME-ALONG AND CABLE ASSEMBLY

A set of come-along cables were used to facilitate the erection of arches. Due to self weight of structure final section of arch ended about 4' outside of base pad and pin location. Therefore, a come-along assembly shown in Figure D-33 was adopted for use. Capacity of the system was 2200 pounds, whereas the horizontal force required to cancel the self weight horizontal reaction was 729.8 pounds.

P. COME-ALONG ASSEMBLY FOR END WALL ARCH

The above come-along assembly had to be modified for use with last arch which carries the fabric end wall. Due to the variation of weight of one rib to another, the horizontal reactions vary considerably. The horizontal reactions of light and heavy arch ribs being respectively as $H_L = 365$ pounds, $H_H = 509$ lbs., the resultant of loading would be:

$$\frac{509}{365} = 1.3945$$

Therefore, a = 40.9271"
b = 57.0729"

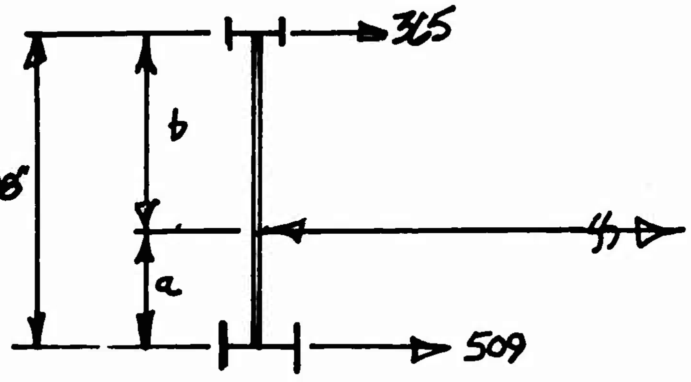


Figure D-32. Loading Resultant

The come-along assembly required modifications to facilitate the end arch erection. (Figure D-33)

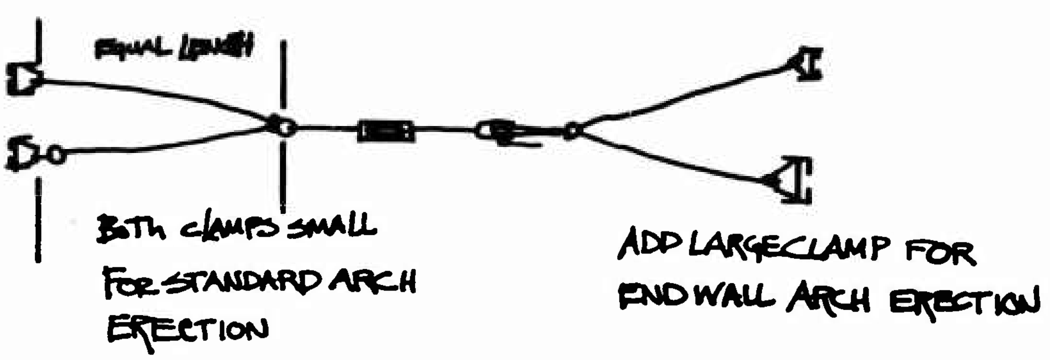


Figure D-33. Come-Along Assembly

Q. UTILITY SHELTER DESIGN

The general configuration and effect of wind loading on this structure is shown in Figure D-34. Many of the components of this structure are interchangeable with the hangar. Simply by inserting hinge links at the knee joints the desired structure is provided.

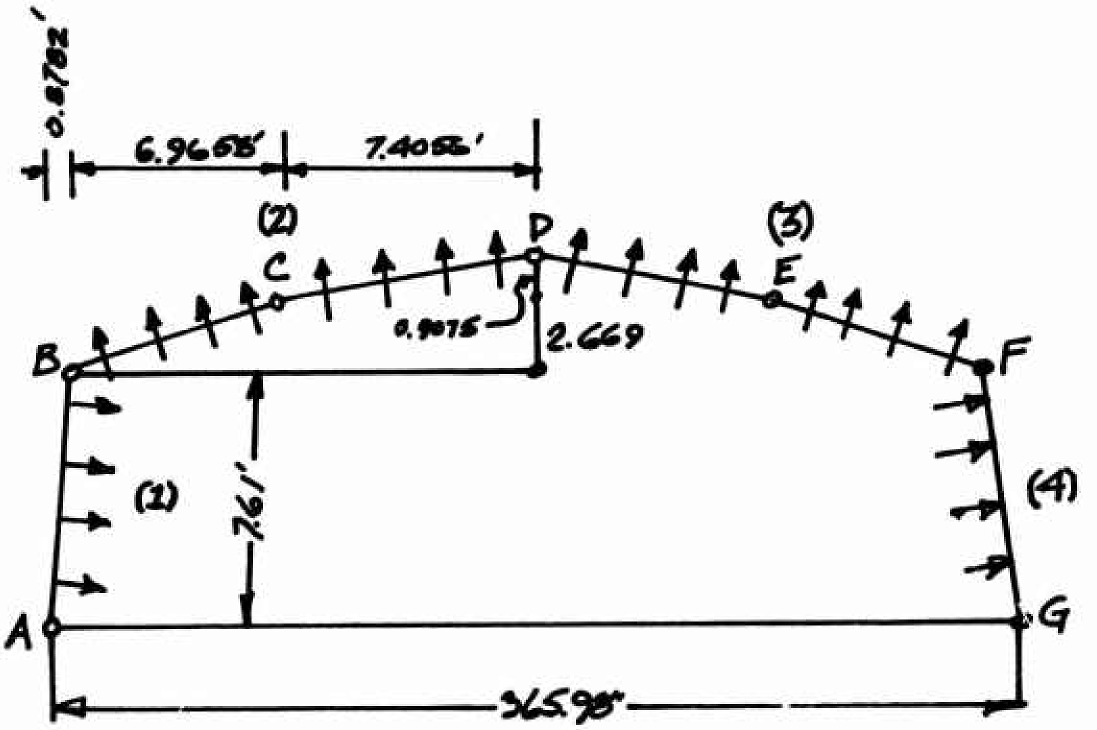


Figure D-34. Arch Loading

The magnitude of each point load, considering the overall size of panels, beams, etc. which are identical to the hangar previously mentioned are as follows:

1. Loads Due to Wind Loading*

	Wind Velocity	
Zone	69	90
1	78.9	134.0
2	38.3	65.2
3	56.3	96.0
4	45.0	76.5

2. Loads Due to Snow Loading*

   In Zones 2 and 3, P = 185 lbs ↓*

*To obtain the loads on this structure the technique used in hangar calculations was employed.

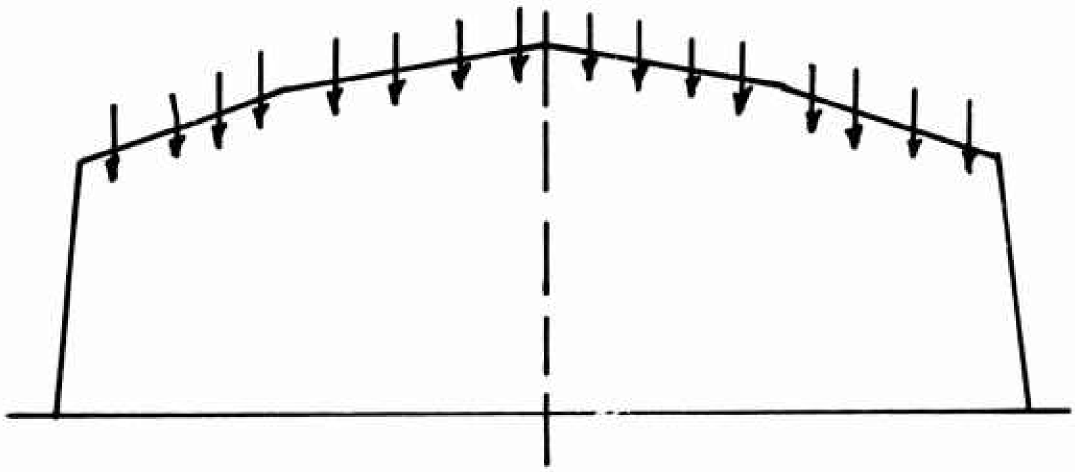


Figure D-35. Snow Loading

A computerized structural analysis was performed for 90 mph wind velocity and snow loading, the results of which is shown in Appendix C.

The bending moments and deflections are shown in Figure D-36.

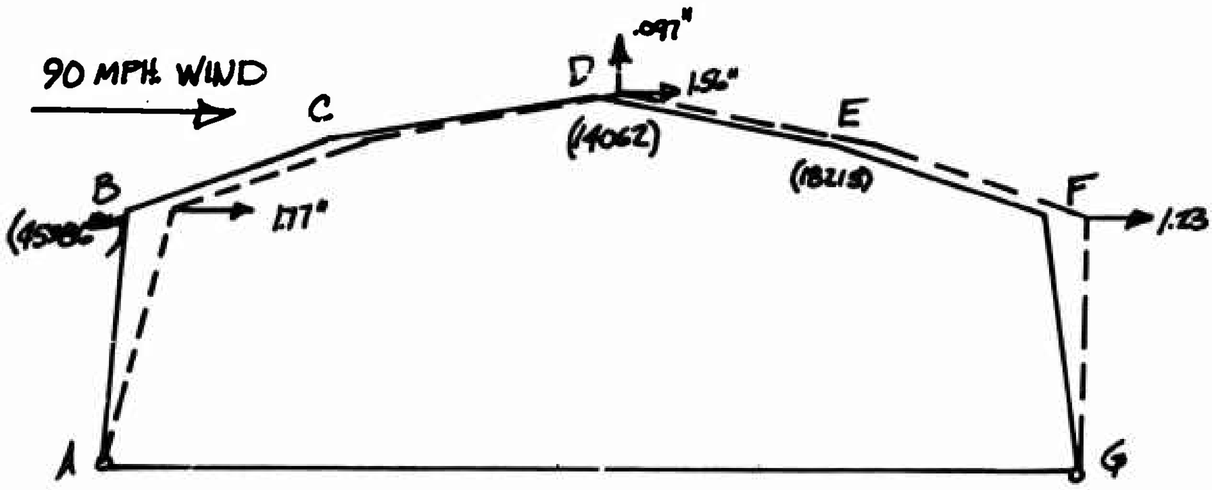


Figure D-36. Arch Deflections

The only critical section for this structure is at the top of the side walls. Therefore, load on the hinge link will be

$$F_T = F_C = \frac{M}{D} = \frac{45465}{5.5} = 8280 \text{ lbs}$$

$$F_1 = 8280 \times \frac{4.5}{4}$$

$$= 9300 \text{ lbs} < 14500$$

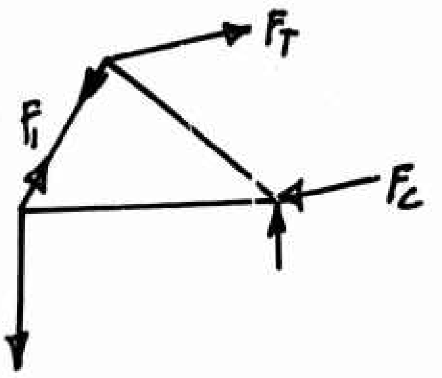


Figure D-37. Loading on Hinge Link

Identical base pads and connectors are used for this structure and hangar, because they were designed for the hangar loadings, they are overdesigned for the Utility Shelter and require no additional design investigation.

APPENDIX E

NEW MATERIAL INVESTIGATION

A. INTRODUCTION

One requirement of the statement of work was to "investigate fabric and flexible plastic film covered foam core materials to replace paper covered materials." The goal was to improve tear resistance, strength, ability to be folded and unfolded numerous times, and cost effectiveness.

This effort was unrelated to the hangar and utility shelters reported on in the body of this report and was directed toward providing a more "rugged" material for 16 x 32 ft. shelters similar to those previously fabricated under Contract AF 33(615)1285. For this reason it is treated as an Appendix in this report.

The work performed to improve the material was performed under this contract (3242) and was so reported in bi-monthly reports #3 and #5 (February-August, 1966). However, as the ultimate aim was to improve the material for shelters still being constructed under amendments to contract 1285, some of the results were incorporated in that portion of the final report of 1285 (Vol. II-AFAPL-TR-65-116) dealing with production of shelters #14 and #15. With the production of the last "folded-beam" concept, 16 x 32 ft. personnel shelter (#16) in August, 1966, no further use of this shelter concept was made. The next use of a scored foam cored board was in the 13 x 35 ft. personnel shelter developed under contract F33615-67-C-1259. A separate effort to improve the board for this different concept was initiated under this contract (3242) by amendment SA/8 5 September 1968. As cited in the Foreword to this report, because this second foamboard improvement effort was directed to application to the 13 x 35 ft. shelter, this effort was reported in the final report of contract 1259.

B. WORK PERFORMED

1. Original Material

The material used for the 16 x 32 ft. shelter fabricated under contract 1285 was "Fome-Cor" 420-A as manufactured by Monsanto. This material consisted of a .250 inch thick polystyrene foam core (average 2.0 lbs/cu ft density) with 42 lb/1000 sq ft Kraft paper facings. The board was coated with two coats (approximately 5 mils) of an epoxy type paint.

While it was recognized that a urethane core might provide a more "rugged" board in some respects, with the withdrawal of Union Carbide "Techni-foam" from the market line in late 1964, no commercially manufactured board of this type was available until late 1966.

2. Attempts to Substitute Plastic for Paper as a Board Liner

It was the initial hope that a board could be located or developed that employed plastic facings instead of paper facings. Rather than having to impart, by post operations, tear resistance, weathering properties and color to Kraft paper, it was hoped that a plastic liner with these properties could be used initially as a skin.

A search of available foam cored sandwich boards revealed that no such plastic faced material was available.

The substitution of a plastic film for the Kraft paper proved to be unfeasible because of the heat required in the laminating process of making the sandwich board. In the available polystyrene board the foam was heated to the point that it in effect heat-sealed itself to the paper liner. A plastic film would not likely withstand this heat. Other problems such as elongation of the film were also anticipated, and no material producer was found who was interested in making experimental runs along these lines. More rigid plastic sheets (i.e., fiberglass reinforced sheets) were not candidates because of the requirement for scoring and repeated folding. As a result of this study, it was decided to retain the Kraft paper liner and concentrate on attempts to improve the ruggedness of the sandwich board by different post-treatments utilizing improvements, coatings, and/or laminates.

3. Post Treatment of Paper Faced Board

Earlier attempts to substitute acrylic paint for the epoxy paint had produced an inferior surface in that moisture absorption through the acrylic was considerable.

a. Urethane Coating

Preliminary investigation suggested that a urethane coating might well produce a more durable coating. Early attempts to apply a urethane coating produced problems due to solvent attack of the polystyrene foam core when the resin penetrated the Kraft paper liners.

This problem was resolved by applying the urethane resin gradually. The first step involved spray-mist coating which was followed by successive light and medium spray applications until the desired thickness was achieved. The manufacturer's recommended cure times were observed between successive coating operations. This entire process was very time consuming and appeared unrealistic in terms of quantity production. However, further tests of the successfully impregnated samples were conducted because of the obvious additional strength they offered.

b. Film Laminates

Several films were investigated as possible facings for the Fome-Cor panels. The most significant disadvantages encountered initially were those of material and bonding costs. In addition, few films could successfully have materials such as cotton webbing, Velcro and coated fabrics contact bonded to them. Only one laminate was chosen for testing. This material was a composite of a 1.5 mil Mylar film and Dacron scrim as used to fabricate weather balloons. Test showed that this laminate had very good local stress or puncture resistance but offered no overall panel stiffness and basic structural integrity.

c. Material Testing

Comparative G. E. Puncture and Mullen tests were performed on sample pieces of Fome-Cor. Table E-I compares various coatings applied to "Fome-Cor" #420-A. This board consists of a .250 inch thick polystyrene foam core faced with 42 lb/1000 sq ft Kraft paper. Table E-II compares various coatings applied to "Fome-Cor" #420-H. This board consists of a .250 inch thick polystyrene foam core faced with 69 lb/1000 sq ft Kraft paper.

d. Test Results

The Mullen and Puncture tests proved the 420-H Fome-Cor with 5 mil Urethane and 1 mil Epoxy paint on both sides superior to other samples. However, further tests revealed that the urethane coated material could not be folded without fracturing the facings along the pre-scored lines. The shelter concept depends on the ability to fold the board and therefore negates the use of urethane as a suitable coating. In addition, it was necessary to paint the urethane coated board to achieve the required color and Ultra-Violet protection. This process had to occur within 24 hours after the urethane had cured to insure proper bonding. A critical time factor such as this could become a major quality control problem in production.

e. Other Paint Tests

The epoxy type coatings investigated proved to be the only systems which satisfied the requirements of imparting to the Fome-Cor strength, color, weather proofing and ability to fold along pre-scored lines. The various tests performed indicated that the Fome-Cor 420-H (having 69 pound Kraft paper facings) with a 5 mil coating of epoxy paint was the most suitable material. The particular paint used was "Aro-Flint 505" as formulated by the Archer, Daniels, Midland Chemical Corporation of St. Paul, Minnesota.

The Contractor conducted several paint tests on panels of Technifoam and Fome-Cor. The paints were Carboline Company Clear #1340 and modified acrylic latex white #3300, and Ocean Chemicals, Incorporated, Flaymbar 2 component #477. The test of

TABLE E-I. COMPARATIVE PANEL TESTS - FOME-COR (420-A)

Board Type And Coating	Weight (Ounce per Square Foot)	General Electric Puncture Test		Mullen Test	
		Individual Readings	Average Reading	Individual Readings	Average Reading
Fome-Cor (420-A) Uncoated	2.063	222 210 215 215	215.5	255 250 250 240	248.75
Fome-Cor (420-A) 5 mil: Urethane Resin: each side	5.255	413 425 410 385	408.25	400 425 450 430	426.25
Fome-Cor (420-A) 5 mil: Epoxy paint: each side	4.779	264 265 265 245	259.75	290 260 290 310	287.50
Fome-Cor (420-A) 5 mil: Urethane Resin and 1 mil: Epoxy Paint: each side	5.455	470 505 436 475	471.50	435 440 410 410	423.75
Fome-Cor (420-A) 1.5 mil: Mylar film/Dacron Scrim Laminate bonded to each side with contact adhesive	3.051	432.5	432.5	--	--

TABLE E-II. COMPARATIVE PANEL TESTS - FOME-COR (420-H)

Board Type And Coating	Weight (Ounce per Square Foot)	General Electric Puncture Test		Mullen Test	
		Individual Readings	Average Reading	Individual Readings	Average Reading
Fome-Cor (420-H) Uncoated	2.94	385 372	378.50	440 420	430.00
Fome-Cor (420-H) 3 mil: Urethane Resin: Each side	4.62	563 507	535.00	495 585	540.00
Fome-Cor (420-H) 5 mil: Urethane Resin: each side	5.19	584 584	584.00	600 585	592.50
Fome-Cor (420-H) 5 mil: Epoxy Paint: each side	5.51	412 448 457 426	435.75	378 373 383 395	382.25
Fome-Cor (420-H) 3 mil: Urethane Resin and 1 mil: Epoxy Paint: each side	4.82	--	598.25	--	542.50
Fome-Cor (420-H) 5 mil: Urethane Resin and 1 mil: Epoxy paint: each side	5.49	--	647.25	--	595.00

the Carboline clear urethane coat web was to determine if it would weatherseal the boards sufficiently to use an acrylic finish coat rather than epoxy. The urethane, as was predictable, attacked the styrene in the Fome-Cor but not the urethane of the Technifoam. The Ocean Flaymbar may have been improperly mixed (no instructions had been submitted) and resulted in a finish which has not dried and is at the same time chalky after three weeks. Results of both sets of tests do not match epoxy in coverage, resistance to bending failures, additional strength for the panel, or appearance.

4. Urethane Foam Board

The folded beam concepts utilized in the 16 x 32 foot shelter developed under Contract AF33(615)1285 requires that the scored components be stored in the flat (unfolded) mode. The memory of the urethane foam means that urethane foam stored flat loses approximately 85% of the groove depth. This meant that, even if a urethane board had been available, the likelihood of its successful application to this problem was slight. (Note: This was confirmed when the last half shelter built under Contract 1285 was fabricated from urethane covered foamboard when it again became available.)

5. Conclusions

While the studies reported above did produce a surface significantly tougher than the previous coating, its tendency to crack when folded made it unsuitable. For this reason, no sample components of the 16 x 32 foot shelter were fabricated.

Shortly after these studies, new personnel shelter concepts were evolved under Contract 1259. These concepts involved storing foamboard components in a folded rather than flat mode and thus made urethane foam a logical core material. As mentioned in the Introduction, this effort has been reported elsewhere in the final report of contract 1259.

XI

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